PB-224 812

INTERMEDIA ASPECTS OF AIR AND WATER POLLUTION CONTROL

Ralph Stone, et al

Ralph Stone and Company, Incorporated

Prepared for:

Environmental Protection Agency

August 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the SOCIOECONOMIC ENVIRONMENTAL STUDIES series. This series describes research on the socioeconomic impact of environmental problems. This covers recycling and other recovery operations with emphasis on monetary incentives. The non-scientific realms of legal systems, cultural values, and business systems are also involved. Because of their interdisciplinary scope, system evaluations and environmental management reports are included in this series.

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

1. Report No.

W 14-00703

4. Title

INTERMEDIA ASPECTS OF AIR AND WATER
POLLUTION CONTROL,

5. Report Date

6.

8. Performing Organization Report No.

Stone, R., and Smallwood, H.

EPA Program Element
1H1093

Ralph Stone and Company, Inc.,
Los Angeles, California.

~~EPA No~~. 68-01-0729

13. Type of Report and Period Covered

12. Sponsoring Organization

Environmental Protection Agency, Socioeconomic Studies Series report ~~number~~,
EPA-600/5-73-003, August 1973. 356p, 30 fig, 51 tab, 411 ref

Current National intermedia pollutants (air, water, and residues) and strategies for their control were evaluated. Major intermedia pollutants in both air and water were identified.

The principal sources of direct intermedia pollutant transfer were identified as incineration, wastewater processing, NO from water chlorination, sludge processing, release of radioactive gases (water-to-air): scrubbers, cleaning equipment, and regeneration of activated carbon (air-to-water). Indirect sources were identified as replacement of fossil fuel by nuclear energy, wastes generated by pollution-control equipment manufacture, and water recycling. Residue disposal problems were found to include landfill gas and leachate contamination, limited disposal sites, and increasing costs. Techniques of controlling intermedia pollutant transfer were found to include prevention, removal, recovery, and conversion; choice between these was found to depend on factors such as physical location, cost, and acceptability. Strategies for preventing intermedia transfer were found to include regulatory (restrictive and prohibitive), economic (incentives and sanctions), and educational. A mathematical model was developed and a gross California South Coast Basin Study conducted. (EPA)

17a. Descriptors *Water pollution*, *Air pollution*, Water pollution control*, ~~Air pollution control*~~, Water pollution sources, ~~Air pollution sources~~. California, *Path of pollutants, Costs, Waste disposal, Waste water treatment, *Air-water interfaces

17b. Identifiers *Intermedia pollution control, ~~strategies*~~, Intermedia transfer*.

(600-73-003)

Copy available from GPO Sup Doc
as EP1.23:1, $3.25; microfiche
from NTIS as PB 224 812, ~~[illegible]~~ $1.45

05B, 05G

19. Security Class. (Report) 20. Security Class. (Page)	21. No. of Pages 22. Price	**Send To:** WATER RESOURCES SCIENTIFIC INFORMATION CENTER U.S. DEPARTMENT OF THE INTERIOR WASHINGTON, D.C. 20240

Albert Herson | Ralph Stone and Company, Inc.

310009

W74-00703

EPA-600/5-73-003
August 1973

PB 224 812

INTERMEDIA ASPECTS OF AIR AND WATER POLLUTION CONTROL

by

Ralph Stone and Herbert Smallwood

Contract No. 68-01-0729
Program Element 1H1093

Project Officer

Roger Don Shull, Ph.D.
Implementation Research Division
Environmental Protection Agency
Washington, D.C. 20460

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $3.15

368

EPA Review Notice

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

Major air and water pollutant control strategies are identified which are of current National concern. Emphasis is on artificial transfer between air or water. Natural transfers are not treated in depth and land is considered only as a means for residue disposal. Discussions include dangers of intermedia transfer from land to air or water.

Control methods for each intermedia pollutant are discussed; comparative costs and expected unit process efficiencies are given. Residue disposal methods and problems are presented.

Institutional factors, regulations and strategies for pollution control are summarized and discussed. These are also illustrated with a gross regional study of the Los Angeles Metropolitan Area, which is described in perspective with the National scene.

Summary data are developed for major pollutants and residues discharged nationally and in the California South Coast Region, along with product/pollutant ratios for industries represented by the Standard Industrial Classification Code and other public economic sectors.

The framework for a mathematical model is developed for the prediction of the effects of change in any of the elements of the production-consumption-pollution-regulation network.

Conclusions and recommendations are given.

This report is submitted in fulfillment of Contract 68-01-0729 under the sponsorship of the Office of Research and Development, United States Environmental Protection Agency.

CONTENTS

Section | Page

I Conclusions 1

II Recommendations 6

III Introduction 8

IV Definitions of Intermedia Terms 16

V The Pollutants, Their Sources and Intermedia Relationships 20
- National Sources of Pollutants 25
- Major Intermedia Air and Water Pollutants (both media) 35
- Major Intermedia Air Pollutant (single medium) 61
- Major Intermedia Water Pollutants (single medium) 73
- Intramedia or Lesser Intermedia Air Pollutants (single medium) 85
- Intramedia or Lesser Intermedia Water Pollutants (single medium) 98

VI Treatment Summaries 117
- Air Pollutant Treatments 117
- Wastewater Treatments 122
- Intermedia Impacts of Process and Treatment 139

VII Regulatory Control Strategy 204

VIII The Mathematical Model 228

IX Regional Case Study 243

X Acknowledgements 302

XI References 303

XII Appendix 333

FIGURES

Figure		Page
1A	CATEGORY RELATIONSHIPS: AIR POLLUTANTS	11
1B	CATEGORY RELATIONSHIPS: WATER POLLUTANTS	12
2	INTERMEDIA FLOW CHARTS: MATERIAL FLOW AND INFORMATION FEEDBACK	21
3	INTERMEDIA FLOW CHARTS: ORGANIZATION AND LEGEND	24
4	INTERMEDIA FLOW CHART: SULFUR OXIDES (GASEOUS)	36
5	INTERMEDIA FLOW CHART: SULFUR COMPOUNDS IN WATER	37
6	INTERMEDIA FLOW CHART: NITROGEN OXIDES	43
7	INTERMEDIA FLOW CHART: NITROGEN COMPOUNDS	44
8	INTERMEDIA FLOW CHART: HEAVY METALS	48
9	INTERMEDIA FLOW CHART: RADIOACTIVE MATERIALS	53
10	INTERMEDIA FLOW CHART: PARTICULATES	62
11	INTERMEDIA FLOW CHART: ORGANICS AND SUSPENDED COMPOUNDS	74
12	INTERMEDIA FLOW CHART: ACIDITY-ALKALINITY	80
13	INTERMEDIA FLOW CHART: PHOSPHORUS COMPOUNDS	83
14	INTERMEDIA FLOW CHART: CARBON MONOXIDE	86
15	INTERMEDIA FLOW CHART: GASEOUS HYDROCARBONS	89
16	INTERMEDIA FLOW CHART: THERMAL POLLUTION	99
17	INTERMEDIA FLOW CHART: PATHOGENS	102
18	INTERMEDIA FLOW CHART: PESTICIDES (HERBICIDES)	108
19	INTERMEDIA FLOW CHART: LIQUID HYDROCARBONS	116
20	AIR POLLUTION CONTROL SYSTEM	208
21	WATER POLLUTION CONTROL SYSTEM	209
22	INTERMEDIA POLLUTION CONTROL: STRATEGY AND POLICY RELATIONSHIPS	210
23	RELATED ELEMENTS IN POLLUTION CONTROL	224
24	STATE AND REGIONAL ENVIRONMENTAL AGENCIES	249
25	SOUTHERN CALIFORNIA AIR QUALITY AGENCIES	250
26	SOUTHERN CALIFORNIA WATER QUALITY AGENCIES	251
27	SOUTHERN CALIFORNIA SOLID WASTE MANAGEMENT AGENCIES	252
28	LBS PER CAPITA SOLID WASTE GENERATION: CITY OF LOS ANGELES	298
29	IMPACT OF SOLID WASTE HANDLING PROCEDURES ON INTERMEDIA MANAGEMENT	299
30	IMPACT OF NON-INCINERATION ON SOLID WASTE DISPOSAL TO LANDFILLS IN LOS ANGELES	300

TABLES

Table		Page
1	POLLUTANT CATEGORIES	15
2	PRIMARY INTERMEDIA POLLUTANTS	17
3	SECONDARY INTERMEDIA POLLUTANTS	18
4	INTERMEDIA MANAGEMENT	19
5	MAJOR POLLUTANTS, SOURCES, AND PRIMARY MEDIA	22
6	NATIONAL SOURCES OF AIR POLLUTION	26
7	NATIONAL SOURCES OF WATER POLLUTION	30
8	SULFUR DIOXIDE WORLDWIDE GASEOUS EMISSIONS	38
9	PRIMARY PARTICULATE EMISSIONS	63
10	ADVANTAGES AND DISADVANTAGES OF COLLECTION DEVICES	65
11	TYPICAL INDUSTRIAL APPLICATION OF WET SCRUBBERS	69
12	SELECTED ESTIMATED VOLUME OF INDUSTRIAL WASTES BEFORE TREATMENT, 1963	76
13	RELATIVE EFFICIENCIES OF SEWAGE-TREATMENT PROCESSES: PERCENT REMOVAL	77
14	INTERMEDIA TRANSFERS IN AIR TREATMENTS	118
15	EQUATIONS FOR CALCULATING ANNUAL OPERATION AND MAINTENANCE COSTS OF AIR TREATMENT METHODS	119
16	CAPITAL COSTS FOR PARTICULATE CONTROL	120
17	ANNUAL CAPITAL AND OPERATING COSTS FOR PARTICULATE CONTROL	121
18	AIR POLLUTION CONTROL EXPENDITURES BY INDUSTRY	123
19	INTERMEDIA TRANSFERS IN WASTEWATER TREATMENT	124
20	WASTEWATER TREATMENT COSTS	125
21	COOLING WATER CIRCULATION (GPM) REQUIRED PER KILOWATT POWER CAPACITY	127
22	VALUES OF K FOR FORCED DRAFT COOLING TOWERS	129
23	RESIDUE DISPOSAL COST RANGES	130
24	RESIDUE DISPOSAL COSTS AS A FUNCTION OF DISTANCE TO DISPOSAL SITE	131
25	COSTS OF INCINERATION AND LAND DISPOSAL AS A FUNCTION OF THE POPULATION SERVED	132
26	RELATIONSHIPS BETWEEN BOD_5 AND SUSPENDED SOLIDS PRODUCED BY INDUSTRY	134
27	RELATIONSHIPS BETWEEN RESIDUE QUANTITIES REMOVED BY WASTEWATER TREATMENTS	135
28	TOTAL LEACHATE QUANTITIES FROM LANDFILLS	137
29	LANDFILL LEACHATE PRODUCTION RATE	138
30	POLLUTION CONTROL ALTERNATIVES AND QUANTIFIED INTERMEDIA IMPACTS	140
30b	AIR TREATMENT RESIDUE DISPOSAL TECHNIQUES	153
30c	WATER TREATMENT RESIDUE DISPOSAL TECHNIQUES	154

TABLES (Cont.)

Table		Page
31	AIR TREATMENT LIST	157
32	WATER TREATMENT LIST	181
33	AMBIENT AIR QUALITY STANDARDS APPLICABLE IN CALIFORNIA	212
34	EXAMPLES OF ADOPTED RULES AND REGULATIONS: SOUTH COAST AIR BASIN	215
35	FEDERAL SURFACE WATER CRITERIA FOR PUBLIC WATER SUPPLIES	217
36	CALIFORNIA DISSOLVED OXYGEN STANDARDS	219
37	REGULATORY STRATEGY CLASSIFICATIONS	221
38	CALIFORNIA LANDFILL SITE STANDARDS	227
39	SOUTH COAST AIR BASIN: COMPARISON OF EMISSIONS BY COUNTY, 1970	255
40	AMBIENT AIR QUALITY STANDARDS APPLICABLE IN CALIFORNIA	256
41	SUMMARY OF RULES AND REGULATIONS: SOUTH COAST AIR BASIN APCD'S	260
42	SUMMARY OF FEDERAL PLAN FOR HYDRO-CARBON REDUCTION	267
43	POLLUTION CONTROLS AND RESIDUES: LOS ANGELES COUNTY, CALIFORNIA	270
44	ESTIMATED WATER USE AND BOD_5 PRODUCTION BY INDUSTRY IN LOS ANGELES	276
45	SEWAGE TREATMENT PLANTS IN THE STUDY REGION	279
46	STUDY REGION LANDFILLS: DISTANCES AND TRAVEL TIMES	292
47	COST SUMMARY OF LONG TERM SLUDGE DISPOSAL ALTERNATIVES	293
48	COSTS OF VARIOUS TRANSPORTATION AND DISPOSAL METHODS	295
49	ENERGY RELATED POLLUTION FOR SLUDGE DISPOSAL	296

APPENDIX

I	ECONOMIC OUTPUT OF SIC-CODED INDUSTRIES	334
II	PHYSICAL OUTPUT OF SIC-CODED INDUSTRIES	338

SUMMARY

1. On the basis of emissions, toxicity, and current conditions, twenty-four pollutants were examined and classified as follows:

Major Intermedia Air and Water Pollutants (both media)
  Sulfur oxides and compounds
  Nitrogen oxides and compounds
  Heavy metals
  Radioactivity
Major Intermedia Air Pollutant (single medium)
  Particulates
Major Intermedia Water Pollutants (single medium)
  Organics
  Suspended solids
  Acidity and alkalinity
  Phosphorous compounds
Lesser or Intramedia Air Pollutants (both media)
  Carbon monoxide
  Hydrocarbons
  Fluorides
  Hydrogen chloride
  Arsenic
  Hydrogen cyanide
  Ammonia
  Ethylene
Lesser or Intramedia Water Pollutants (single medium)
  Thermal
  Pathogens
  Pesticides
  Metallic salts and oxides
  Chlorides
  Surfactants
  Liquid hydrocarbons

Their SIC Code sources and the total quantity of the aforementioned pollutants, and the major problems created, are tabulated and discussed in the body of the report.

2. Principal physical control techniques include: (a) treatment for removal, (b) conversion to non-pollutants (c) recovery for reuse, (d) manufacturing process changes to achieve a change in waste materials or quantities, (e) cessation of production or non-use of a particular polluting material.

3. Principal regulatory methods for stimulating the use of these physical methods include: (a) regulatory controls that are either restrictive or prohibitive in nature, (b) economic controls in the form of other incentives or sanctions (taxes, etc.), and (c) educational campaigns to stimulate changes in habits, etc.

4. Principle methods for the conversion of pollution discharges to an alternate medium include incineration, wet scrubbing, solids removal with landfilling, land application of effluents or sludges, recovery and reuse with transformed waste products.

5. Residue disposal problems include gas and leachate generation (ground and surface water pollution) contamination through erosion, runoff, and other natural processes; availability of land; costs of land and transportation; social and environmental acceptability of the disposal methods; increasing quantities of residues requiring disposal; and the increasing number of toxic materials in the residues.

6. Comparative cost information for various control methods has been prepared and tabulated in the body of the report.

7. The critical factors influencing the choice of pollution control techniques and the discharge medium are physical location of the process, concentration of other dischargers, environmental acceptability of the waste products, costs of the control method, opportunity for product recovery, established discharge standards, consequences of not meeting these standards, and residue disposal problems already mentioned.

8. The gross regional study of the general Los Angeles Metropolitan Area (South Coast Basin) outlines the existing State and local administrative structure for pollution control, lists the manufacturing production processes in use, waste control facilities, waste products produced, regulations, their implementation, and projections for the future.

9. Section VII – Strategies and Implementation–discusses a conceptual framework for a total environmental program approach.

SECTION I

CONCLUSIONS

The following conclusions are arranged in accordance with the Contract Task Requirements listed in the introduction.

TASK I INTERMEDIA POLLUTANTS AND THEIR SOURCES

1. The major intermedia pollutants emitted initially to either air or water are: sulfur compounds, nitrogen compounds, heavy metals and radioactivity. Those initially discharged to water are: organics, suspended solids, acidity and alkalinity, and phosphorus compounds; those discharged initially to air are limited to particulates.

2. Intramedia or lesser intermedia air pollutants are carbon monoxide, hydrocarbons including ethylene, fluorides, hydrogen chloride, arsenic, hydrogen cyanide and ammonia. Intramedia or lesser intermedia water pollutants are: pathogens, pesticides, thermal pollution, metallic salts and oxides, chlorides, surfactants, and liquid hydrocarbons.

2. The major sources of air pollution and their respective Standard Industrial Classification Codes are: mobile sources, power generation from fuel (491), chemicals manufacture (28), metallurgical processes (33) and refuse incineration (4953). Large contributors of particulates to the atmosphere include: the sand, clay and glass industry (32) and non-metal mining and quarrying (14).

3. The major sources of water pollution are: agriculture (01, 02), food processing (20), mining (10, 11, 12), paper and allied products (26), chemicals manufacture (28), blast furnaces and basic steel production (331), and sanitary systems and sewers (4952).

TASKS II, III, IV CONTROL AND DISPOSAL PROBLEMS AND TECHNIQUES

1. Intermedia transfers include direct transfer (removal of a pollutant from one medium and its disposal in another) or indirect (pollution created in another medium and usually in another form by a basic change in a process or industry).

2. The principal current sources of direct intermedia transfers from water to air are:

Incineration of sewage sludge or other industrial waste residues including radioactive wastes.

Ammonia, other gaseous and volatile emissions from wastewater aeration processes, trickling filters, lagoons, stripping towers, sewers, etc.

Nitrous oxide emissions from chlorination for ammonia nitrogen control in water.

Sewage and industrial waste sludge digestion and drying.

Removal of radioactive gases from reactor coolant water and their release following insufficient storage time.

Direct intermedia transfers from water-to-air which are avoidable only with considerable expense are usually of minor significance. They result from wastewater treatment processes such as aeration, trickling filters, lagoons, stripping towers, anaerobic decomposition and chlorination for removal of ammonia nitrogen. The air pollutants produced are nitrogen oxides, hydrogen sulfide, methane, mercaptans and ammonia.

3. The principal current sources of direct intermedia transfers from air to water are:

The use of scrubbers to control gaseous emissions to the atmosphere.

Flushing with water to remove and carry residues from dry collection equipment such as cyclones.

Steam regeneration of activated carbon used to control gaseous emissions, although this depends upon the subsequent treatment of the steam condensate and the resulting volatilized or oxidized materials.

4. The principal current sources of indirect intermedia transfers are:

Replacement of fossil fuel power generation by nuclear power generation. This eliminates hydrocarbon, particulate, sulphur dioxide, nitrogen oxides and other forms of air pollution from fossil fuel combustion, but it creates possible radioactive pollution of air and water and thermal pollution of water.

Waste products created by the manufacture of pollution control equipment.

Recycling of water to reduce water usage. This seemingly intramedial alternative may create indirect intermedia transfers by the reduction of production efficiency from the buildup of salinity or scale in either process or cooling equipment. A reduction in efficiency results in an increased new materials and labor input to maintain production rates and the accompanying increased outputs to the environment of more energy, waste materials, people, greater travel and the additional support services required.

TASK V COMPARATIVE CONTROL COST INFORMATION

1. A mathematical model (WARM) described in this report incorporates the interrelationships between regional transportation alternatives (mass transit and private automobile) and regional pollution control strategies. Additional factors, such as industrial zoning and land-use planning, are important in determining transportation planning and control strategies. A simultaneous analysis of all relevant factors is necessary for arriving at optimal pollution-control decisions.

2. The available data is inadequate for the effective implementation of intermedia pollution control strategies; although considerable information is available for certain problems of direct intermedia transfers, data insufficiencies were noted for indirect transfers. Because of the need for coordinated planning, this data deficiency is a serious one. While dollar input-output relationships are helpful, they are not sufficient to evaluate the intermedia pollution relationships within the mathematical model described in Section VIII of this report (WARM) or a similar model. Specific information concerning physical input-output relationships for the various economic sectors is needed.

TASK VI CRITICAL FACTORS AFFECTING CHOICE OF CONTROL TECHNIQUE AND DISCHARGE MEDIUM

1. Physical location of the process.

2. Concentration of other dischargers.

3. Opportunity for product recovery.

4. Environmental acceptability of waste products. Since waste treatments alter the form or concentration of waste material, rather than destroying it, waste treatments that are single-medium oriented many times offer incomplete pollution control, since they may result in undetected, but significant, intermedia transfers.

5. Costs of the control method. The effectiveness of any legal strategy seeking to provide regulatory control will depend on three factors: the costs of compliance, the costs of noncompliance, and the probability of enforcement. Costs of the control method, included within the costs of compliance, involve factors such as the costs of research and development to generate new control technology, the additional capital and operating costs of meeting regulatory specifications such as emissions standards, and the costs associated with lag time or inconvenience while the control method is being implemented.

6. Established discharge standards and consequences of not meeting these standards. Strict enforcement of discharge standards depends on conscientious licensing procedures, adequate pollutant monitoring, impartial staffing of control agencies, and sufficient control agency funding and personnel to inhibit evasive practices as well as more obvious violations of discharge standards. The consequences of not meeting established discharge standards, such as fines for violation, must be severe enough so that noncompliance with established standards is discouraged.

TASK VII GROSS REGIONAL STUDY

1. Air pollution control has had a much larger impact on solid waste quantities than has water pollution control. In the City of Los Angeles, where virtually all wastewater is discharged to the sewer system, the disposal of all sewage sludge to the land would increase the dry weight of total solid waste disposed by only 2.5 percent. In contrast, a return to the 1957 burning and air pollution standards would now reduce solids disposal to landfills about 43 percent by weight.

2. Few incinerators can meet the rigorously established emission standards of Los Angeles County; for strategic reasons, incinerators, which are a relatively expensive form of residue treatment, should be de-emphasized and residues disposed to landfills or reclaimed for agriculture.

TASK VIII ADDITIONAL RESEARCH REQUIRED, GENERAL CONCLUSIONS, CONCEPTUAL FRAMEWORK, AND STRATEGIES.

1. Systematic industrial waste data concerning air pollutants, their sources, quantitites economic and environmental effects are better documented and inventoried than those relating to water pollutants. Available information concerning liquid industrial wastes consists largely of unrelated case studies at various industrial plants with resulting data estimates of low reliability.

2. The ambient standards for water have not been as well correlated with discharge standards as those for air, since enabling data is seldom available.

3. Many toxic waste residues are the result of intermedia transfers, since historically many toxic waste residues have been disposed broadly by dilution into the environment.

4. Since more efficient dry collection methods exist for most applications where scrubbers are currently employed, reasonable alternatives to air-to-water transfers are available. Where scrubbers must be used, settling basins can be utilized to create a solid residue.

5. Indirect intermedia transfers seem to be of greater significance than direct transfers, but the latter, when occurring between air and water should be avoided, and generally can be by utilizing alternative technology including land disposal in an adequately designed and operated facility which protects the public health and prevents subsequent intermedia pollution transfers to air and/or water.

6. Strategies to prevent intermedia pollution include avoidance of processes and materials which produce the pollutants as well as the treatment of the waste discharges. Elimination of potential pollution may be more efficient than treatment as a pollution control strategy.

7. The effectiveness of regulatory control strategy depends primarily on the relative anticipated costs of compliance or noncompliance with legal requirements. Three sets of factors are involved: the costs of compliance and of noncompliance, and the probability of enforcement.

The major costs associated with compliance are: the cost of research and development to generate approved technology; the additional capital and operating costs of meeting emission standards or other regulatory specifications; and the inconvenience or time lag associated with the development of or conversion to approved technology, equipment, or devices. The major costs associated with noncompliance, or violation,are: fines, imprisonment, withholding of licenses, unfavorable publicity, and legal expenses. Strict enforcement depends on: conscientious licensing procedures; adequate sufficient funding and personnel to inhibit both outright violations and evasive practices such as dilution of emissions by increasing air/water use, selective operation of control equipment when inspection is anticipated, and night discharges.

There is little economic motivation to comply with regulatory standards if the anticipated financial penalty is equal to or less than the anticipated increase in amortization/operating costs associated with compliance. If the penalties are set at a realistic level for the purpose of dissuading violation, the probability of detection and enforcement must be sufficiently high to make the anticipated cost-benefits of compliance more attractive than those of contravention.

8. There is a need for further coordinated planning to optimize comprehensive programs for environmental protection, including close regional coordination of transportation, industrial zoning and land use planning, and regional pollution control strategies.

SECTION II

RECOMMENDATIONS

As a result of this study and the conclusions drawn from it, the following recommendations are intended to make present pollution control strategies more effective and develop a better understanding of intermedia pollution transfers' processes and impacts, as well as to provide for developing better decision-making tools.

1. Greater emphasis should be given to obtaining a balance in the programs and control strategies which are directed either toward the regulation of pollutional activities or toward the financial and/or technical assistance given to reducing, abating or preventing pollution. To accomplish this balance, it is necessary to develop and/or perfect a means for assessing the consequences of any intended action within a controlling geographical area including the effects of additional production, consumption, importation, exportation, or transfer of materials, energy, and waste products.

2. The mathematical model (WARM) outlined in this report should be further developed and expanded along with the necessary inventory of input information to assist in the assessments described above. The information concerning physical input-output relationships is particularly necessary. Although a complete physical input-output representation of the economy may not be feasible in the near future, enough information should be developed to evaluate the pollution control strategies on an incremental basis. This approach, while not able to evaluate all indirect implications of the strategy, would be a step in the right direction.

3. Specific intermedial regional studies are needed along with better and more complete inventories of pollution strategies, processes, products, controls, discharges and pollutants for the establishment of reliable mass balances within each area. These intermedial regional studies should be representative of areas of weak, average, and strong pollution control programs. The study areas would also be candidates for application of the mathematical model noted in Recommendation 2.

4. There should be further investigations of the detailed composition of industrial wastewater discharges to augment the sparse information presently available.

5. More data should be gathered concerning the fate of pesticides and heavy metals present in incinerated wastes.

6. Further studies should be made of the fate of heavy metals and other toxicants present in waste sludges disposed to the land.

RECOMMENDATIONS (Cont.)

7. Further research is needed to improve the technology for controlling intermedia transfers of many of the pollutants. Those presently existing are largely the result of expeditiously solving an immediate and obvious problem, and do not necessarily offer satisfactory control.

8. Further research is needed concerning the conversion of waste materials to non-pollutants and how they may be recovered and reused.

9. Alternative methods for residue control are limited essentially to source reduction, environmental diffusion, land burial, or burning. As residues continue to increase rapidly in volume and weight, further studies should be directed toward reclamation, improved treatment, transportation and process of disposal.

All of the above recommendations are directed toward providing a wider range of intermedia pollution control strategies, social-economic benefits, and the means for choosing optimum system alternatives.

SECTION III

INTRODUCTION

Objectives and Scope

As set forth in the contract,the program objectives were summarized in 8 tasks:

1. List the major intermedia pollutants to air and water, their source by Standard Industrial Classification Code, and the problems they cause.
2. Describe the principal control and residue disposal techniques.
3. Describe the method(s) which could convert discharges to the alternate medium.
4. Describe residue disposal problems.
5. Develop comparative control cost information.
6. Identify the most critical factors affecting choice of control technique and discharge media.
7. Perform a gross regional case study of intermedia pollution management.
8. Draw conclusions, suggest additional research, and develop a conceptual framework for a total environmental protection program approach.

The study's primary concern is with the intermedial impact of air and water pollution control strategies and to a lesser extent the environmental management of residues created by removing pollutants from air and water. The analysis has evaluated factors such as inputs required, products created and costs that influence choices of controls or alternative processes. Particular efforts have been made to study the intermedia effects of control alternatives.

Previous pollution control strategies have had poor overall coordination with the result that intermedia impacts have been neither predicted nor assessed. For example, formerly many products of incineration have been diverted by control programs from the air to the water and the land without consideration of the consequences. Historically,emphasis on removal rates or dilution capability has been used to control pollution,as illustrated in water quality control by the stress placed on percent removal of suspended matter and BOD_5. Percent removal is a partial and simplistic consideration. The most relevant questions are these: Into what form are the major pollutants converted? What will be done with the new residues? What environmental impacts result, or what are the intermedia implications of this pollution control strategy?

This report has attempted to focus on significant variables of man-made pollution as contrasted with natural pollution. It does not treat to any large degree problems that are not of major importance in the total national pollution program, nor with situations which we cannot now practically affect. Natural processes will be described only where man's activities are significantly interrelated.

Area of Study

The work program has emphasized nationwide considerations. A secondary activity has involved a gross regional evaluation. The national technological and institutional framework of intermedia pollution has been applied to the gross regional study of the South Coastal Basin of Southern California. The peculiarities of the region have been noted insofar as they depart from national data in economic activities, costs, plant and treatment processes used, etc. For example, coal combustion is a major source of power and heat nationally, and is a major source of air pollution. However, in Southern California coal is a minor consideration and natural gas, water, and nuclear energy are the prime sources of power and heat. Included in the South Coast Region are the metropolitan and agricultural flatlands of Ventura, Los Angeles, San Bernardino, Orange and Riverside Counties; the mountainous zones which surround the air basin are excluded.

Method of Analysis

All national economic sectors have been considered as potential pollution sources. These activities are presented in accordance with the United States Department of Commerce's 2-digit Standard Industrial Classification (SIC) categories. Consumer and public activities have also been evaluated as major pollution sources. An input-output structure has been designed to describe economic activities and the resultant major pollution loads within one large matrix. To determine which were the major intermedia pollutants a candidate list of all major air and water pollutants was first developed, based on extensive studies of available national pollution data. Each identified pollutant was evaluated for intermedia relationships to yield the list of major intermedia pollutants.

Terminology

Significantly, it was necessary to re-orient the conventional knowledge of single media "tunnel" viewpoints to overall environmental "intermedia" viewpoints. Common terminology was confused and considerable effort was expended to define major intermedia pollutants and other related language.

Presentation of Data

The estimates of total quantities of pollutants discharged into the air and water are expressed in consistent terms, such as tons/yr. For the input-output matrix these relationships are reduced to lbs/$ value of the product produced by each industrial sector. The ambient pollutant concentration levels are expressed in mg/l for water and in ppm for air. The unit "ppm" is independent of temperature and pressure in air, whereas mg/l is not since it is an expression of weight per volume of air.

Data Sources

Data for this project was obtained from materials at the libraries of the University of California at Los Angeles, the Los Angeles Library of the Department of Commerce and the Library of Ralph Stone and Co., Inc. Numerous journal articles, reports of governmental agencies, conference reports, magazine and newspaper articles, various pamphlets, and pollution monographs were used as sources of information. A standard abstract form was designed and adopted for referencing, sorting, and entering acquired data. Emphasis has been placed on publications published recently within a five year period; however, older classical data have also been used when current information was lacking.

In each case the most current available data has been used. Similarly, the most recently derived coefficients expressing the amount of pollutant per unit of product were determined from the literature, and then gross quantities of pollutants were updated to the year 1971 with separate additional information that was gathered on industrial output for that year.

Future Applications

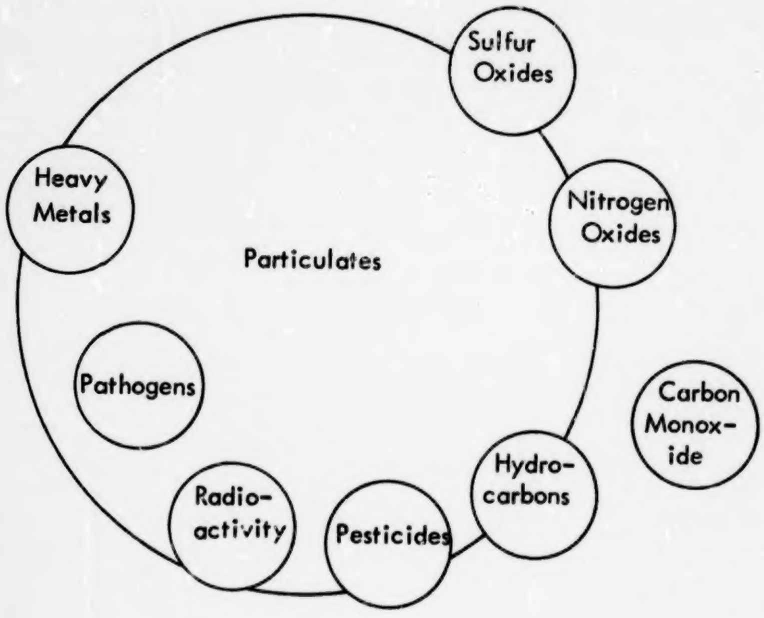
In most cases consideration of waste treatments is separated from that of production process changes. Process changes are generally better long-term solutions to pollution problems but are more difficult to put into effect quickly. Waste treatment usually may be applied with minimum delay. Neither the waste treatments nor the production process changes discussed in this report are intended for the distant future. Emphasis has been placed on current technology which can be applied to present systems.

Application of the Data

The report also presents a specific analysis for a sample sector of the economy. Sector 28, Chemicals and Allied Products, was used as a typical case study of pollution control strategies and the intermedia effects. The gross regional study is also presented as an analytical example of applied intermedia pollution control strategies.

Major Pollutant Category Relationships

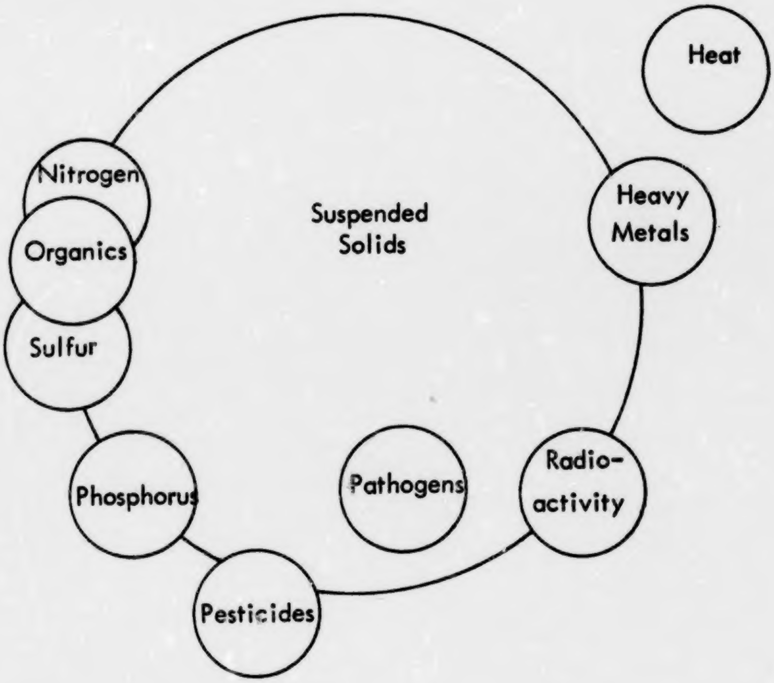
The currently recognized pollutant categories have evolved on the basis of their effects on the environment. Because of this, the categories tend to overlap in terms of their physical composition. The Venn diagrams of Figures IA and IB represent the relationship of one single medium and intermedia major pollution category for air and water respectively. Figure IA shows the major air pollutants; note that the particulates category only partially includes heavy metals, radioactivity, pesticides, hydrocarbons, nitrogen oxides and sulfur oxides, while the particulates category totally includes pathogens and totally excludes carbon monoxide.


Particulates
Sulfur Oxides
Nitrogen Oxides
Carbon Monoxide
Hydrocarbons
Pesticides
Radioactivity
Pathogens
Heavy Metals

VENN DIAGRAM

Example: Sulfur Oxides may be in particulate form or not.

FIGURE 1A
CATEGORY RELATIONSHIPS
AIR POLLUTANTS


Heat
Nitrogen
Suspended Solids
Heavy Metals
Organics
Sulfur
Phosphorus
Pathogens
Radio-activity
Pesticides

Example: Nitrogen and Sulfur may appear either as suspended or dissolved organic or inorganic compounds.

FIGURE 1B
CATEGORY RELATIONSHIPS
WATER POLLUTANTS

Air and Water Pollutant Categories

Pollutants are described herein as air or water, according to the medium in which they create the primary pollution problem. If a pollutant creates a problem in both media and land, it is described for each medium and classified according to the medium in which the greatest quantity is present. Table 1 presents these categories and the pollutants they contain.

Figure 1B shows the major water pollutant category of suspended solids, and its more complicated intersections with other categories. Organic material not only occurs as suspended solids but also is composed of nitrogen and sulfur compounds. An intersection between two circles in these two charts represents a significant coincidence between two such pollutants. For example, it would be possible to have radioactive heavy metals,but they are shown separately in Figure 1B as this latter overlapping interrelationship with other pollutant categories is of no great significance.

Pollutant Categories

Three considerations have been used in classifying pollutants in this report: the primary medium in which the pollutant occurs, its intermedial properties, and its national impact. Thus the pollutants are currently categorized as air or water pollutants, as intermedial or intramedial, and as major or lesser national pollutants. Table 1 breaks the commonly-known pollutants into these various categories.

Major vs. Lesser Pollutants

Except for acidity and alkalinity, only major pollutants are dealt with in this report. Acidity and alkalinity are discussed because considerable information was gathered on them prior to deciding to class them as lesser pollutants. Liquid hydrocarbons due to oil spills or poor waste treatment are a serious point problem in surface waters but not nationally. Also, the existing controls for this latter pollutant are intramedial.

In order for a pollutant to be currently classified as a major pollutant it must present a current problem of national significance, or pose a potential near-future problem. Thus, even though a pollutant such as fluorides could be a serious problem in a local area, it is not included in the list of major pollutants. The less important pollutants and the reasons for their not being classified as major pollutants are presented in the following sections.

Intermedial vs. Intramedial Pollutants

A pollutant is not classified as an intermedial pollutant unless it can be transferred in a significant degree from air to water or water to air by processes or activities of man. Natural intermedia transfers are not included. "In a significant degree" means that intermedia pollution transfer occurs at a level where evaluation of current technology is necessary. Thus, emissions of pesticides and herbicides during their manufacture can be controlled with intermedial treatments, but the major pollution problem stems from their application to crops, trees, etc.,and resulting food chain effects,rather than from their manufacture. Pesticide and herbicide pollution cannot be controlled by the defined intermedial processes, and therefore these pollutants are classified as intramedial.

TABLE I

POLLUTANT CATEGORIES

	AIR		WATER	
	Intermedial	Intramedial	Intermedial	Intramedial
Major	Nitrogen oxides	Carbon monoxide	Phosphorous compounds	
	Sulfur oxides	Hydrocarbons	Sulfur compounds	Pesticides
	Particulates		Nitrogen compounds	Pathogens
	Heavy metals		Organic material	Liquid Hydrocarbons
			Suspended solids	
			Heavy metals	
			Radioactivity	
Lesser	Radioactivity			Acidity/Alkalinity
	Fluorides	Arsenic	Thermal	Chlorides
	Hydrogen chloride			Metallic Salts and Oxides
		Hydrogen cyanide		Surfactants
		Ammonia		
		Ethylene		

SECTION IV
DEFINITIONS OF INTERMEDIA TERMS

For the purposes of this project, the following definitions have been adopted. The order in which they are listed is intended to facilitate understanding to a greater extent than would an alphabetical arrangement.

MEDIA (singular, MEDIUM): The water and air in which a pollutant may be present, or through which a pollutant may be conveyed.

a) For the purposes of this project, land is not considered as a medium, although residues are created that may be ultimately disposed to the land. Residue disposal to land is evaluated, especially with reference to possible subsequent transfers to the air or water (leaching, etc.)

INTERMEDIA: Concerning transferability from one medium to another.

INTRAMEDIA: Concerning transferability within a medium or concerning pollutants not transferable between the two fluid media.

POLLUTION: The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of an environmental medium. (Based on Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972.)

POLLUTANT: Any material which contributes to the pollution of an environmental medium.

MAJOR POLLUTANT: Any pollutant which is or may be injurious to the public health or welfare. Welfare is broadly understood to include total socio-economic and environmental impact. The pollutant must be of national significance now or capable of becoming so within the next two years.

MAJOR INTERMEDIA POLLUTANT: Any material capable of transfer between media and which is recognized by the regulatory agencies as having significant national negative impact on either or both media.

PRIMARY INTERMEDIA POLLUTANT: A pollutant which is transferable from one medium to another in the same or similar form.

SECONDARY INTERMEDIA POLLUTANT: A major pollutant which is transferable from one medium to another in an altered chemical form.

INTERMEDIA TRANSFER PROCESS: The physical, chemical, and biological means by which a pollutant is transferred from one medium to another. (The project is concerned only with processes subject to human control.)

INTERMEDIA MANAGEMENT: The manipulation of pollution control activities such that optimum improvement and maintenance of the total environment is sought, and one medium is not managed at the expense of another.

POLLUTION CONTROL STRATEGY: Art or science applied in support of national policy to reduce or eliminate intermedial pollution.

RESIDUE: Matter remaining at the end of a process.

Examples of primary intermedia pollutants, secondary intermedia pollutants, and intermedia management are given respectively in Tables 2, 3, and 4.

TABLE 2

PRIMARY INTERMEDIA POLLUTANTS

	Equivalent Pollutant by Medium		
Pollutant	Air		Water
Oxides of Nitrogen	NO_2	→	NO_3^-
	↑		
	NO	→	NO_2^-
Oxides of Sulfur	SO_2		$SO_3^=$
		→	
	SO_3		$SO_4^=$
Particles	Particulates	⇄	Suspended Solids
		⇄	Dissolved Solids
Pathogens	Pathogens	⇄	Pathogens
Thermal	Heat	⇄	Heat

TABLE 3

SECONDARY INTERMEDIA POLLUTANTS

Originating Medium	Pollutant Transfer Process	Final Medium
Water		Air
Organic Solids:		
suspended and dissolved	Combustion	CO Hydrocarbons Oxides of Nitrogen Oxides of Sulfur
Organic Solids	Anaerobic decomposition	H_2S CH_4

TABLE 4

INTERMEDIA MANAGEMENT

Pollution Control Activity	Example
Change of Process	Change from the sulfite process in pulp manufacture to mechanical shredding
Change of Material	Replacement of mercury seals in trickling filters with vinyl or butyl rubber
Change in Land Use	Moving electroplating plants away from positions adjacent to water courses
Change in Activity	Replacement of the gasoline powered private automobile with electric or steam powered mass transit

The above manipulations do not solve pollution problems, but they do shift either the medium receiving the pollutants or the location of pollution and, therefore, aid in arriving at a more easily controlled situation.

SECTION V
THE POLLUTANTS, THEIR SOURCES AND INTERMEDIA RELATIONSHIPS

INTRODUCTION

In this section the intermedial flows of the pollutants under consideration will be analyzed since there is considerable interchange between the pollutant categories. For example, suspended solids or particulates may be burned to create carbon monoxide, sulfur, nitrogen oxides or most other forms of air pollution. The flows of each pollutant have been analyzed separately and where a pollutant is treated in such a way as to change its form, a reference note indicates the intermedia flow chart on which its treatment and disposition continues. In this way valuable insights into the intermedial flows are given.

In Section VI, Control Summary, information about particular treatments is presented and the implications of these methods are discussed.

Pollutant and Product Flows

Figure 2 represents the overall relationships involved in this study of intermedia pollution. It includes the pollution generating activities, inspection, ambient sampling and feedback and control mechanisms. The parts of this sytem that can be influenced by hyman decisions will be reflected in a mathematical model, to be discussed in Section VIII.

Figure 2 shows production activities stemming from human needs. These production activities produce pollutants as well as physical output. The consumption of this output in turn gnerates its own pollution. Certain options are open to society in controlling pollutants produced by production, distribution and consumption. Figure 2 illustrates the fact that these control activities can cause resultant problems in alternative media. The natural responses by the media are also shown although these are not the primary focus of this report. Information flows are shown by dotted lines; these lines represent the feedback mechanism in the system. Both ambient sampling and plant inspection feed information to influence control decisions which in turn affect production and consumption decisions.

Figure 2 also illustrates the possibility of recycling wastes and residues and the adverse effects of pollution on the nation's resources.

Major Pollutants and Their Sources

Table 5 illustrates,in a qualitative way, the major intermedia sources of air and water pollution. For water, the major contributors are domestic sewage, pulp and paper manufacture, chemical production, food processing and the basic metal refineries. Nuclear power plants, of course, can contribute to radioactivity and heat in the water. The greatest contributors to air pollution relate to combustion processes. They include mobile sources, fossil fuel combustion, petroleum refineries, basic metal refining, and pulp and paper production. Again, nuclear power plants may contribute radioactivity to the atmosphere.

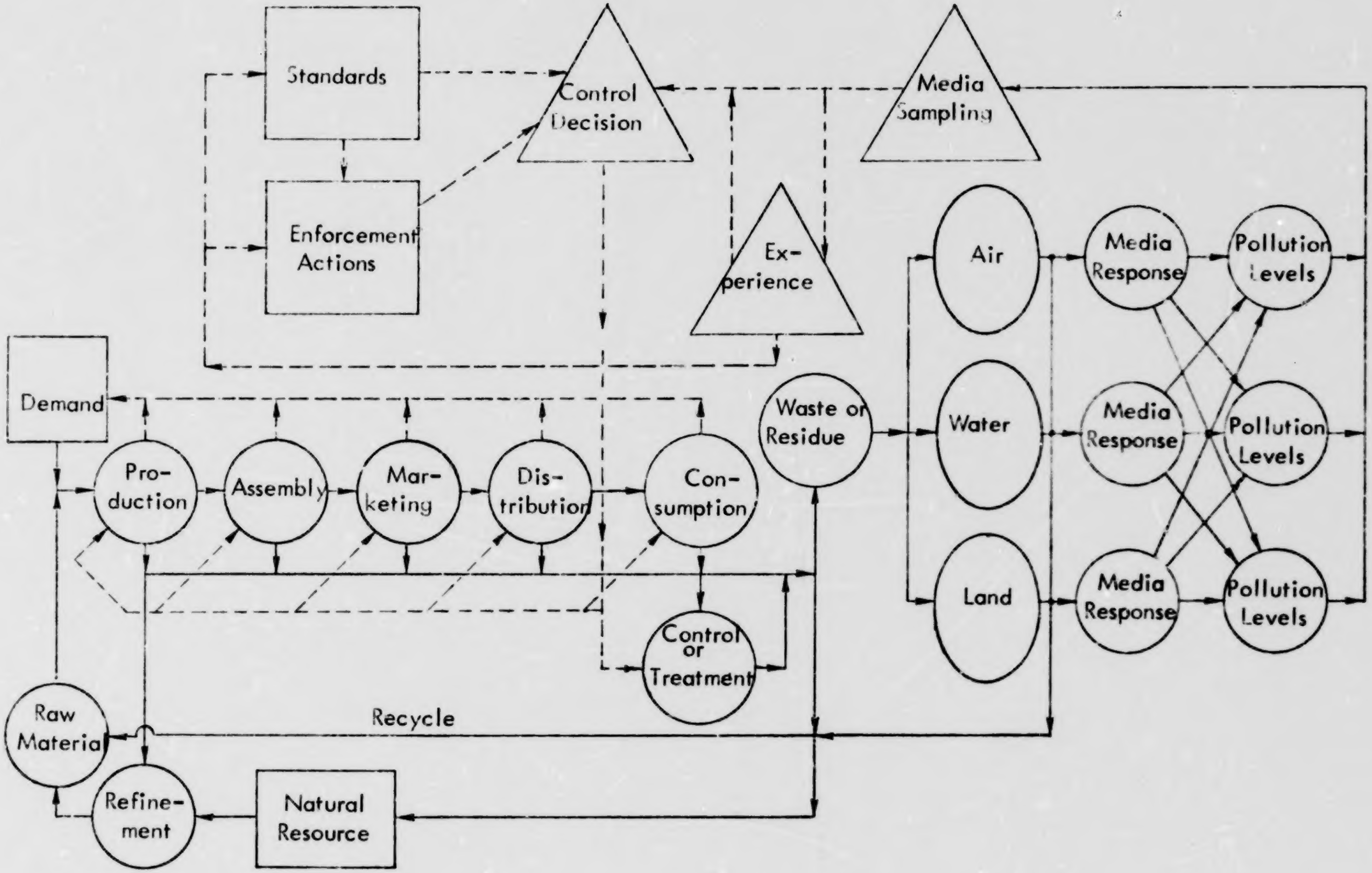

Standards
Enforcement Actions
Control Decision
Media Sampling
Ex-perience
Demand
Pro-duction
Assembly
Mar-keting
Dis-tribution
Con-sumption
Control or Treatment
Waste or Residue
Air
Water
Land
Media Response
Media Response
Media Response
Pollution Levels
Pollution Levels
Pollution Levels
Recycle
Raw Material
Refine-ment
Natural Resource

FIGURE 2
INTERMEDIA FLOW CHARTS
MATERIAL FLOW AND INFORMATION FEEDBACK

TABLE 5

MAJOR POLLUTANTS, SOURCES AND PRIMARY MEDIA

SOURCE	WATER									AIR					
	ORGANICS	SUSP. SOLIDS	SULFATES, PHOS., NITRATES	HEAVY METALS	ACIDITY-ALKALINITY	PATHOGENS	THERMAL	RADIOACTIVITY	PESTICIDES	NITROGEN OXIDES	SULFUR OXIDES	CARBON MONOXIDE	HYDROCARBONS	PARTICULATES	RADIOACTIVITY
BASIC METALS[a]		●	●	●	●					●	●			●	
FOOD PROC.[b]	●	●	●											●	
CHEM. & ALLIED[c]	●	●	●	●	●				●		●		●	●	
PULP & PAPER[d]	●	●	●		●						●	●		●	
PETROLEUM[e]					●					●	●	●	●	●	
COAL, OIL COMB.[f]										●	●	●	●	●	
NUCLEAR POWER[g]							●	●							●
DOM. SEWAGE[gj]	●	●	●		●	●									
MOBILE SOURCES[h]										●		●	●	●	
AGRICULTURE[i]									●						

a Standard industrial classification (SIC) code: 33
b SIC code: 20
c SIC code: 28
d SIC code: 24,26
e SIC code: 29
f All users of coal, and oil
g SIC code: 49
h SIC 40,41,42,45 private vehicles
i SIC 01,02
j Including urban runoff

Format Description

The major pollutant categories shown in Table 5 will be discussed in this section. There is direct intermedial relationship between sulfur oxides and sulfur compounds and also between nitrogen oxides and nitrogen compounds, and between air and water forms for pesticides, heavy metals, and radioactive wastes. These categories, therefore, are combined for both their air and water forms into one discussion. The other major pollutants will be described in separate sections on air and water. Some liquid hydrocarbon information has been appended to the hydrocarbon discussion given under air pollutants as no similar major water pollutant category has been established here. Liquid hydrocarbons do not represent a major intermedial transfer of airborne hydrocarbons but are a lesser, though important, separate problem created by the petroleum industry. Thus the pollutants will be discussed under three main headings: (1) air and water pollutants, (2) air pollutants, and (3) water pollutants. The air and water pollutant categories will be presented in the order they are shown in Table 5.

Intermedia Flow Charts

Throughout this section, the intermedia flows of the pollutants will be represented on intermedia flow charts. Figure 3, "Intermedia Flow Charts, Organization and Legend," explains the symbols and organization of these charts. At the top of each chart the major sources of the pollutant are represented in rectangles. The treatment alternatives are then represented as circles, while the media to which the pollutants are routed are represented as ellipses located at the bottom of the sheet. Arrows represent the directions of the flows and decision points in the flow charts. The use of these arrows is also illustrated in the legend.

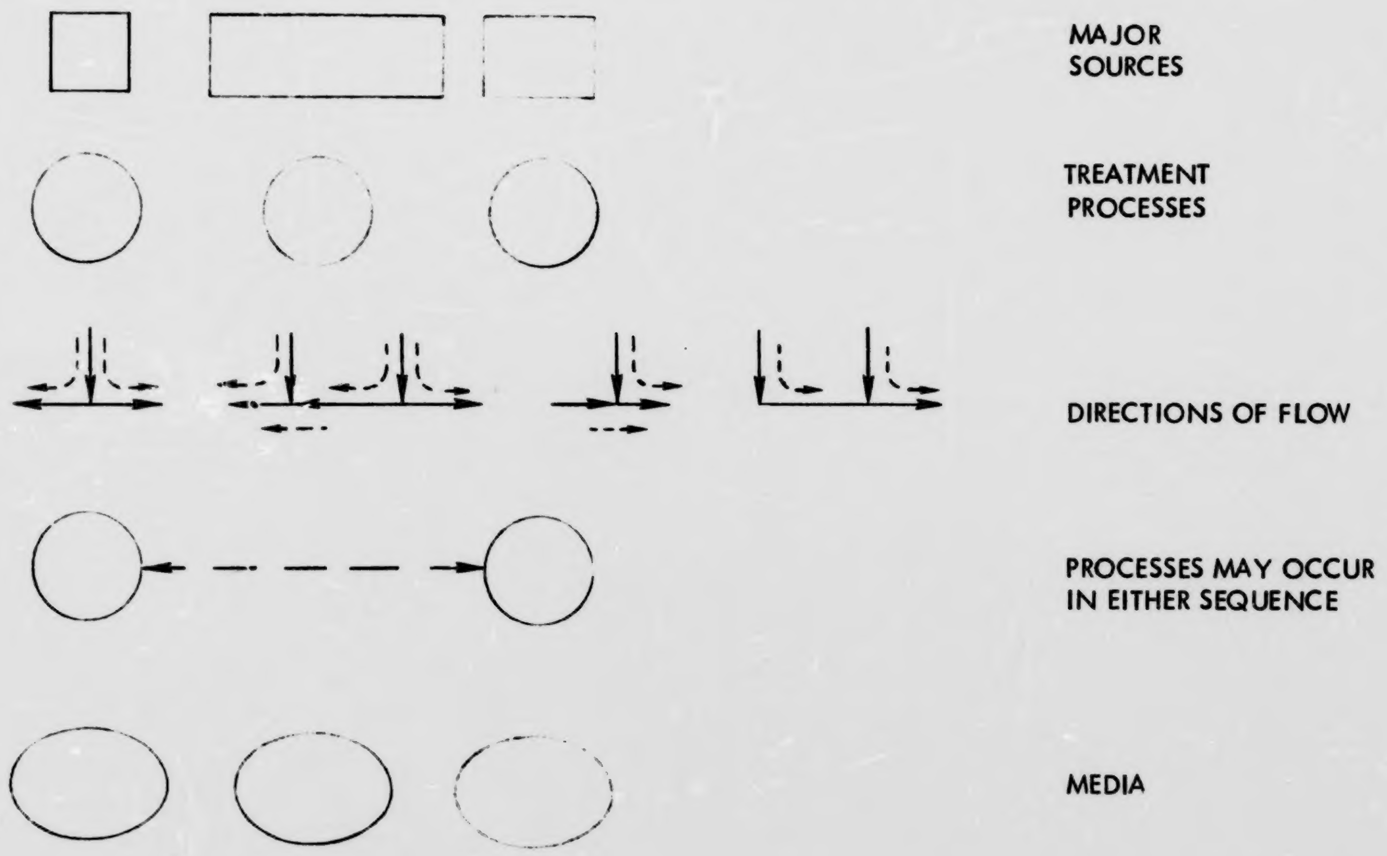

MAJOR SOURCES
TREATMENT PROCESSES
DIRECTIONS OF FLOW
PROCESSES MAY OCCUR IN EITHER SEQUENCE
MEDIA

FIGURE 3
INTERMEDIA FLOW CHARTS
ORGANIZATION AND LEGEND

NATIONAL SOURCES OF POLLUTANTS

Tables 6 and 7 summarize the national sources of air and water pollution by Standard Industrial Classification (SIC) sectors. The significant SIC sectors for the mathematical model are shown. Where possible, the data were standardized for the base year, 1971. Sectors are presented for which quantitative information was found. The Tables were prepared by multiplying pollution coefficients per unit of industrial output by the physical output information. Appendix Table II lists typical examples of some physical output data. Where physical output data was available for an earlier period, the outputs were updated using the ratio of dollar output in that year to the dollar output in 1971. Appendix Table I summarizes the 1971 dollar output figures. Obviously, when original data were earlier than 1970, the dollar output ratios were adjusted to account for inflation.

The pollution coefficient tables were not included in the Appendix because of their volume, size and complexity. The coefficients are, of course, dependent upon the processes used and the treatments applied to the pollution emissions. Where possible, data were gathered on the degree of use of alternative processes by industry and calculated total pollutant outputs by industrial sectors. Uncontrolled discharges were assumed except when available data indicated the extent of waste treatment. In general, comprehensive data were not available to indicate the extent of the use of various waste controls by industry. The data used to evaluate alternative assumptions about treatment strategies are presented in Section VI, Treatment Summaries.

Air Pollution. Table 6 is more complete than Table 7. The totals were reconciled with EPA figures for 1970 from "Environmental Quality."[14] Considering the limited available data and the general lack of information on SIC Code treatment levels, the numbers compare favorably. Where data are incomplete, Table 7 so indicates.

Water Pollution. The total quantity of water pollutants shown in Rable 7 differs considerably from that noted in certain other sources. As an example, "The Water Encyclopedia," published by the Water Information Center, indicates 22,000 million pounds of BOD_5 discharged by industry in 1963.[41] This contrasts sharply with the 14,105 million pounds shown in Table 7 for 1971. These differences probably occur because of inadequacies of present pollution data sources.

TABLE 6

NATIONAL SOURCES OF AIR POLLUTION

		Pollutants (Millions of Pounds/Year)					
SIC	Name	Sulfur Oxides	Nitrogen Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Radio-activity
01	Agriculture Crops			---[a]		---	
02	Agriculture - Livestock						
08	Forestry			549	2,100	1,777	
10	Metal Mining			25,500			
11	Anthracite Mining	---					
12	Bituminous Coal and Lignite Mining	---					
13	Oil and Gas Extraction						
14	Non-Metal Mining and Quarrying			15,504			
201, 202	Meat and Dairy Products			---	---		
203	Processed Fruits and Vegetables						
204	Grain Mill Products			3,334			
Misc. 20	Misc. Food Products			2			
22	Textile Mill Products			202			
24	Lumber and Wood Products			34(P)[b]		13(P)	
26	Paper and Allied Products	220		6,650	3,078		

TABLE 6 (cont.)

NATIONAL SOURCES OF AIR POLLUTION

SIC	Name	Sulfur Oxides	Nitrogen Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Radio-activity
		Pollutants (Millions of Pounds/Year)					
281	Industrial Inorganic Chemicals	1,171		45	2,744	1,235	
282	Plastic Materials and Synthetics					32	
283	Drugs						
2873	Nitrogenous Fertilizers						
2874	Phosphate Fertilizers						
2879	Agriculture Chemicals nec[c]						
2895	Carbon Black			1,875	5,540	985	
Misc. 28	Misc. Chemicals			---	---	---	
291	Petroleum Refining	4,800	602	970	30,773	3,025	
295	Paving and Roofing Material			1,068	1	1	
31	Leather and Leather Products						
324	Cement Hydraulic			14,624			
325	Structural Clay Products			431			
327	Concrete Gypsum and Plaster		33	7,897			
Misc. 32	Misc. Fiber Glass			---			
331	Blast Furnace and Basic Steel Production	1,000		21,669	1,177	2,382	

TABLE 6 (cont.)

NATIONAL SOURCES OF AIR POLLUTION

		Pollutants (Millions of Pounds/Year)					
S!C	Name	Sulfur Oxides	Nitrogen Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Radio-activity
332	Iron and Steel Foundries		3	1,511	2,007		
333	Primary Non-Ferrous Metals	7,432		366			
334	Secondary Non-Ferrous Metals			377			
336	Non-Ferrous Foundries - Castings			66			
34	Fabricated Metal Products					10	
36	Electric and Electronic Equip.					32	
37	Transportation Equip.						
40	Railroad Transportation	215	294	98	275	196	
42	Warehousing and Trucking	640	9,344	589	7,936	1,510	
44	Water Transportation						
45	Air Transportation	23	66	46	3,812	628	
491	Electric - Power Generation Services	40,000		50,500	198	127	- - -
492	Gas Production and Distribution		- - -			- - -	
4952	Sanitary Systems Sewers						
4953	Refuse Disposal Systems	200	800	2,800	14,400	4,000	

TABLE 6 (cont.)
NATIONAL SOURCES OF AIR POLLUTION

		Pollutants (Millions of Pounds/Year)					
SIC	Name	Sulfur Oxides	Nitrogen Oxides	Particulates	Carbon Monoxide	Hydro-carbons	Radio-activity
54	Food Stores						
5541	Gasoline Sales[d]	5,540	14,984	1,015	173,576	33,422	
72	Dry Cleaning					- - -	
	Totals	61,241	26,131	157,722	247,617	49,375	
	1970 EPA Data	68,000	46,080	50,000	294,000	70,000	

[a] Data gap. This sector contributes to this pollutant, but quantitative information is incomplete.

[b] Partial data. This sector contributes more of this pollutant than shown here but quantified information is incomplete.

[c] Not elsewhere classified.

[d] Includes all pollution generated by private automobile use.

TABLE 7

NATIONAL SOURCES OF WATER POLLUTION

Pollutants (Millions of Pounds/Year)

SIC	Name	Sulfur Compounds (as S)	Nitrogen Compounds (as N)	Heavy Metals	Organic BOD$_5$	Suspended Solids	Acidity Alkalinity	Phosphorous Compounds (as P)	Radio-activity
01	Agriculture - Crops		8,250					- - -	
02	Agriculture - Livestock		1,000						
08	Forestry								
10	Metal Mining								
11	Anthracite Mining								
12	Bituminous Coal and Lignite Mining	2,200					7,000[d]		
13	Oil and Gas Extraction				- - -				
14	Non-Metal Mining and Quarrying								
201, 202	Meat and Dairy Products				2,298	1,187			
203	Processed Fruits and Vegetables				988	467			
204	Grain Mill Products								
Misc. 20	Misc. Food Products				48	13 (P)[b]			
22	Textile Mill Products				330	459	- - -		
24	Lumber and Wood Products				- - -	- - -			

TABLE 7 (cont.)
NATIONAL SOURCES OF WATER POLLUTION

SIC	Name	Pollutants (Millions of Pounds/Year) Sulfur Compounds (as S)	Nitrogen Compounds (as N)	Heavy Metals	Organics BOD_5	Suspended Solids	Acidity Alkalinity	Phosphorous Compounds (as P)	Radio-activity
26	Paper and Allied Products				7,898	3,286	---		
281	Industrial Inorganic Chemicals				471	4,450	---	11	
282	Plastic Materials and Synthetics				579	331	---		
283	Drugs				25	46			
2873	Nitrogenous Fertilizers	1	4		6	26			
2874	Phosphatic Fertilizers				---	47		41	
2879	Agriculture - Chemicals nec[c]				58	6			
2895	Carbon Black								
Misc. 28	Misc. Chemicals				99	184			
291	Petroleum Refining	39	70		268	164	---	6	
295	Paving and Roofing Material								

TABLE 7 (cont.)

NATIONAL SOURCES OF WATER POLLUTION

SIC	Name	Sulfur Compounds (as S)	Nitrogen Compounds (as N)	Heavy Metals	Organics BOD_5	Suspended Solids	Acidity Alkalinity	Phosphorous Compounds (as P)	Radio-activity
		Pollutants (Millions of Pounds/Year)							
31	Leather and Leather Products				187	530	- - -		
324	Cement, Hydraulic								
325	Structural Clay Products								
327	Concrete, Gypsum and Plaster								
Misc. 32	Misc. Fiber Glass					- - -	- - -		
331	Blast Furnace and Basic Steel Production			18	238	1,870	- - -		
332	Iron and Steel Foundries				14	47	- - -		
333	Primary Non-ferrous Metals				5	256			
334	Secondary Non-ferrous Metals					- - -			
335	Non-ferrous Drawing, Rolling and Extruding				7	49			
336	Non-ferrous Foundries - Cast					- - -			
34	Fabricated Metal Products			- - -			- - -		
36	Electric and Electronic Equip.								

TABLE 7 (cont.)
NATIONAL SOURCES OF WATER POLLUTION

SIC	Name	Pollutants (Millions of Pounds/Year) Sulfur Compounds (as S)	Nitrogen Compounds (as N)	Heavy Metals	Organics BOD_5	Suspended Solids	Acidity Alkalinity	Phosphorous Compounds (as P)	Radio-activity
37	Transportation Equipment				36	40			
40	Railroad Transportation								
42	Warehousing and Trucking								
44	Water Transportation								
45	Air Transportation								
491	Electric - Power Generation Services						---		1,200^e
492	Gas Production and Distribution								
4952	Sanitary Systems - Sewers	960	2,400		8,006	9,651	---	540	
4953	Refuse Disposal Systems								
54	Food Stores								
5541	Gasoline Sales								
72	Dry Cleaning								

TABLE 7 (cont.)
NATIONAL SOURCES OF WATER POLLUTION

SIC	Name	Pollutants (Millions of Pounds/Year) Sulfur Compounds (as S)	Nitrogen Compounds (as N)	Heavy Metals	Organics BOD_5	Suspended Solids	Acidity Alkalinity	Phosphorous Compounds (as P)	Radio-activity
	Totals	3,200	11,724	18	22,111	23,109	7,000 (p)[d]	598	1,200[e]
	Totals Without Domestic Sewage	2,240	9,324	18	14,105	13,458	7,000	58	1,200

[a] Data gap. This sector contributes to this pollutant, but quantitative information is incomplete.

[b] Partial data. This sector contributes more of this pollutant than shown here but quantified information is incomplete.

[c] Not elsewhere classified.

[d] Millions of pounds of $H_2 SO_4$ (sulfuric acid).

[e] Millions of curies (mega curies).

MAJOR INTERMEDIA AIR AND WATER POLLUTANTS (BOTH MEDIA)
SULFUR OXIDES AND COMPOUNDS

Intermedia Relationships

In Figures 4 and 5 the sources, treatment and fate of sulfurous wastes are summarized to show their intermedial relationships. Intermedia transfer of sulfur compounds between the water and air may occur directly (water scrubbing of gaseous exhausts) or indirectly (leaching and runoff from residues deposited on land, and incineration of sulfur-containing sludges). Regardless of the mode by which it is accomplished, transfer to water from air generally is much more easily accomplished than transfer to air from water. The net result of this is that watercourses tend to become the ultimate sink for sulfur emissions in the absence of biodegradation to volatile products (H_2S) or environmentally isolated deposit on land. Natural processes are estimated to be responsible for a great portion of incidental intermedia transfer of sulfur compounds (biological decomposition and sea spray), but their relative contribution tends to be inversely proportional to population density.

Environmental Impact

Sulfur dioxide may easily be oxidized in the air to SO_3, and both compounds have destructive environmental impacts. Exposures to SO_2 concentrations of 3-4 ppm may occur in urban atmospheres[57] but no persistent effect on humans has been detected for these levels. At 5 ppm human exposure for an hour may cause choking.[5] Some evidence exists that sulfur dioxide and certain sulfur compound aerosols produce a toxicity synergism.[3, 58] The hydrate of SO_3 is sulfuric acid, which is more toxic than SO_2 or its hydrate H_2SO_3. Sulfuric acid is 4-20 times as physiologically damaging to animals as SO_2.[59] The Air Conservation Commission of the American Association for the Advancement of Science states: "sulfuric acid must have been the principle cause of air pollution disasters in the Meuse Valley, Germany; Donora, Pennsylvania; and London, England."[5] As a result of the conversion of SO_2 to H_2SO_4, sulfur dioxide is especially injurious to plant life, being phytotoxic to some species in concentrations as low as 0.1 to 0.2 ppm.[60] Necrotic blotching and streaking are the chief symptoms,[61] and photosynthesis may be inhibited or terminated.[5]

By the action of H_2SO_3 or H_2SO_4, metals and other materials may be corroded or degraded, especially when moisture is present.[62] Sulfur dioxide may be a major contributor to visibility reduction in urban atmospheres, as its great hygroscopicity allows the formation of aerosol droplets in the size range of less than one micron; this is most effective in scattering visible light.[63] Bluish-white plumes from industrial and power plant stacks, as well as hazes in industrial regions, are often attributable to the presence of SO_3 and H_2SO_4.[5] Oxides of sulfur may easily be washed by rainfall from the atmosphere as sulfite salts and are oxidized to sulfates. Sulfate compounds are

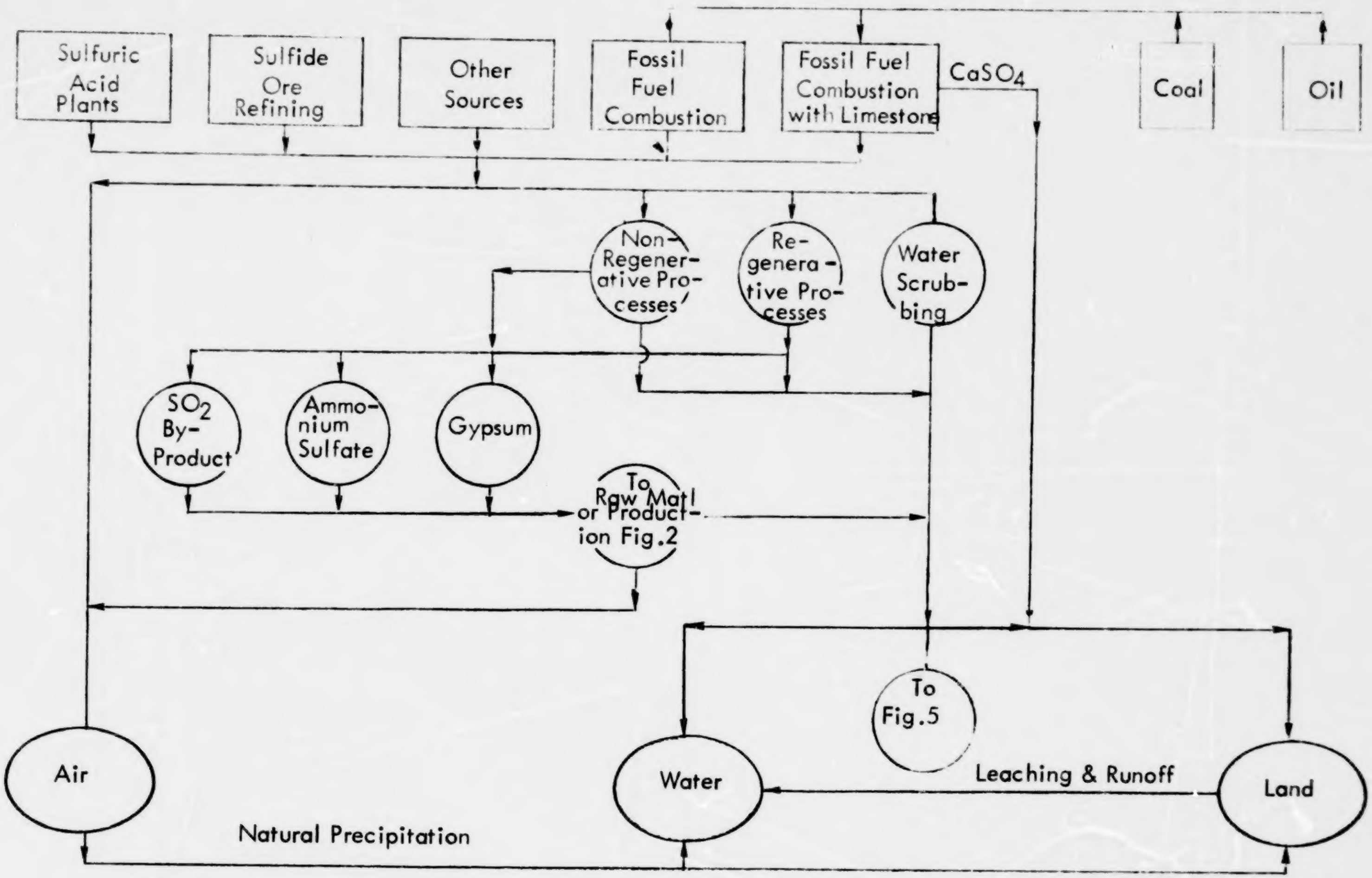

Sulfuric Acid Plants
Sulfide Ore Refining
Other Sources
Fossil Fuel Combustion
Fossil Fuel Combustion with Limestone
$CaSO_4$
Coal
Oil
Non-Regenerative Processes
Re-generative Processes
Water Scrubbing
SO_2 By-Product
Ammonium Sulfate
Gypsum
To Raw Mat'l or Production Fig.2
To Fig.5
Air
Water
Land
Leaching & Runoff
Natural Precipitation

FIGURE 4
INTERMEDIA FLOW CHART
SULFUR OXIDES (GASEOUS)

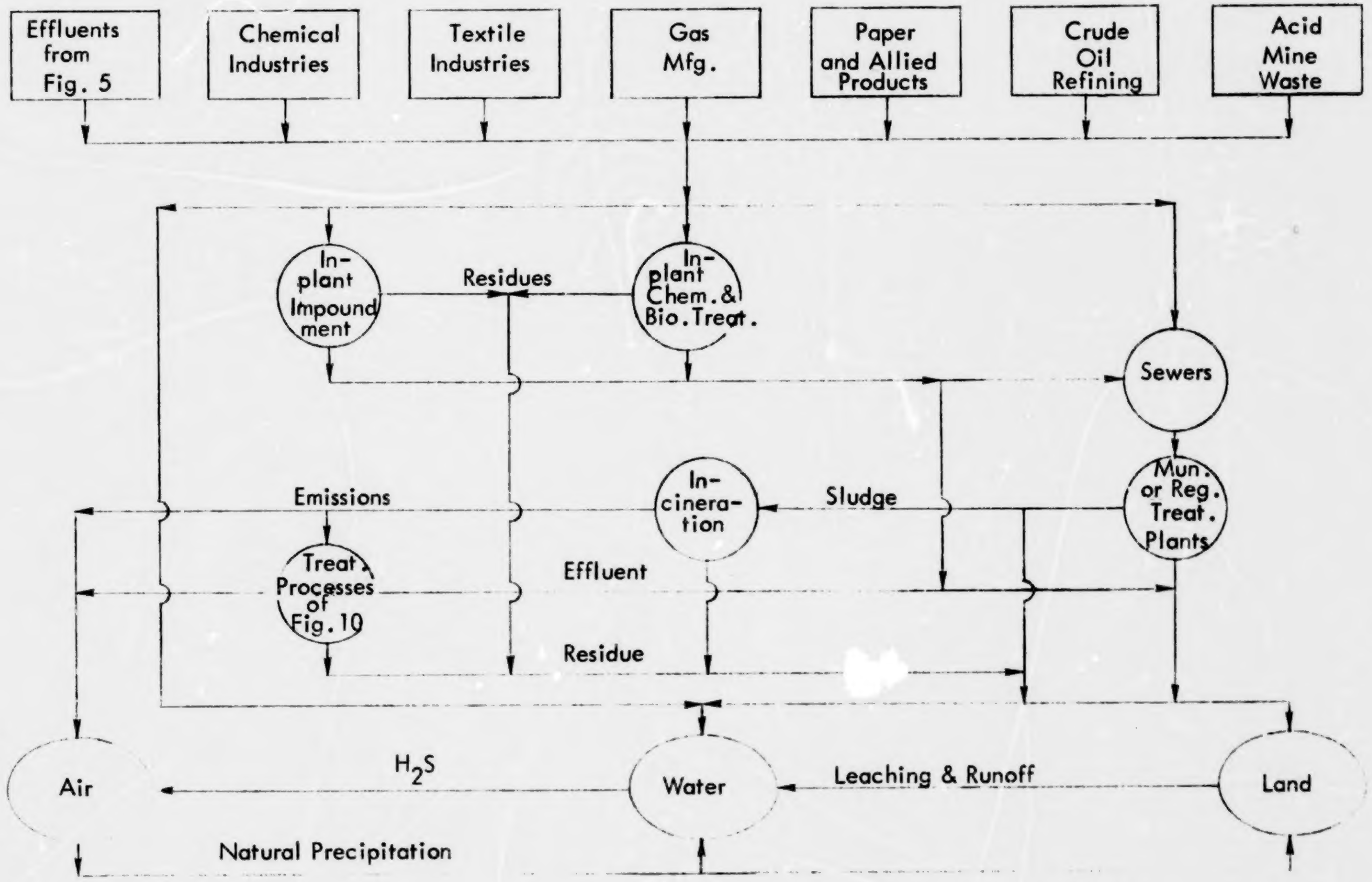

Effluents from Fig. 5
Chemical Industries
Textile Industries
Gas Mfg.
Paper and Allied Products
Crude Oil Refining
Acid Mine Waste
In-plant Impoundment
Residues
In-plant Chem. & Bio. Treat.
Sewers
Emissions
In-cineration
Sludge
Mun. or Reg. Treat. Plants
Treat. Processes of Fig. 10
Effluent
Residue
Air
H_2S
Water
Leaching & Runoff
Land
Natural Precipitation

FIGURE 5
INTERMEDIA FLOW CHART
SULFUR COMPOUNDS IN WATER

negligibly degradable and they will tend to leach into surface and subsurface water supplies after deposition onto the land. These effects were noted near Ducktown, Tennessee, 30 years after initiation of the recovery of sulfur dioxide formerly discharged into the atmosphere from copper smelting operations. Waterborne sulfur compounds also can be damaging. In addition to their presence in liquid wastes from SO_x scrubbers, several primary sources of sulfur compounds in water are known. Chemicals and allied products,[64,65] textile mill products, gas manufacture, and paper and allied products are major contributors of sulfur compounds to waste water.

Effluents with excessive contents of sulfur compounds are objectionable because they may anaerobically generate sulfides which are malodorous and even toxic. The recommended maximum sulfate concentration for drinking water in the United States, where no other source of water is available, is 250 mg/l.[67] Above that level gastrointestinal irritation may result.[68] Various sulfur compounds in water have been shown to have a toxic effect on fish. For example, the toxic concentration of sodium sulfide for fish is about 3.2 mg/l and of dissolved hydrogen sulfide is about 0.5 to 1.0 mg/l.[69] Hydrogen sulfide[70] is toxic and has caused the death of many sewer workers. It has an offensive "rotten egg" odor, blackens lead paints, copper and brass, and causes corrosion of concrete.[66] A concentration of 200 mg/l sulfur compounds renders water undesirable for irrigational use, and a 500 mg/l concentration is excessive if the water is used to water cattle or other stock.[70]

Main Sources of Sulfur Oxides

The main sources of airborne sulfur oxides are fossil fuel combustion and sulfide ore refining. Table 8 lists world gaseous emissions of sulfur dioxide.[71]

TABLE 8

SULFUR DIOXIDE WORLDWIDE GASEOUS EMISSIONS

Source	Total SO_2 (10^6 tons)
Coal	102
Petroleum combustion & refining	28.5
Smelting	
Copper	12.9
Lead	1.5
Zinc	1.3
Total	146.2

Use of Alternative Processes

Sulfur dioxide pollution may be reduced by substitution of alternate processes, such as nuclear, solar, or geothermal energy sources for electric power production or fossil fuel combustion. Retaining fossil fuel combustion, but switching to fuels with low sulfur content, such as natural gas, is currently (1973) a popular control method that is widely applied. Pre-cleaning of fossil fuels to remove sulfur is possible but relatively costly.[72] Increased combustion efficiency may reduce SO_2 emissions, but it increases conversion to SO_3.[5]

Treatments

Some of the treatment processes enable recovery of valuable products. They are already in common use in applications where the concentrations are high and the potential recovery value is significant. Current problems lie more with sources that generate emissions significant in their impact on pollution but not of a sufficiently high level that internal economics make removal treatment attractive. Regulation of emissions is changing this pattern. The processes that recover the product in usable form are applicable mainly to the high concentration emissions, while the non-recovery systems usually are more efficient for low-concentration emissions. Metallurgical processes that handle sulfur-containing ores are the primary high concentration sources. Fuel combustion and sulfuric acid manufacture generate low concentration emissions.[18] Treatment costs are presented in Section VI insofar as they are available.

Dilution

Treatment by dilution utilizes stacks which may be as high as 800 feet or more. This can be somewhat effective in reducing nearby ground level SO_x concentrations. The method takes advantage of the dilution capacities of air and is not an intermedia treatment. It has been shown that the maximum downwind ground-level concentration is inversely proportional to the square of the effective stack height,[18] which is the physical stack height plus the plume rise as influenced by the exit velocity of the gas, the difference in density between the gas and the atmosphere, and the meteorological conditions. Treatment methods will be further discussed in the summary of controls, Section VI.

Steam Regenerative Sulfur Dioxide Removal Processes:

Dimethylaniline Process This process absorbs SO_x by a countercurrent contact of the gas stream with a dimethylaniline (DMA) solution. The gas stream is further treated with Na_2CO_3 and H_2SO_4 solutions to remove any DMA carried over and SO_2 which escapes absorption. The SO_2 is released from the DMA by contact with steam. The latter is then filtered and decanted to remove any water before return to the absorber. The SO_2 is then dehydrated before being sold or used. This process reportedly is 99 percent effective in gas streams containing 5.5 percent sulfur dioxide. Data indicates this process is suitable only for high concentrations of SO_2 and is relatively expensive. Many sulfuric acid plants use this or a similar process.

Sulfidine Process This process is similar to the DMA process except a mixture of xylidine and water is used in a 1·1 ratio and there are some other minor changes. It is adaptable to gas streams with SO_2 concentrations of 1 to 16 percent, and produces SO_2 as a by-product.

Ammonia Process Sulfur dioxide is removed by contact with ammonium sulfide, and the resulting ammonium sulfite is regenerated by steam. This process yields SO_2 which is usually converted to sulfuric acid.

Basic Aluminum Sulfate Process Sulfur dioxide is removed by contact with a solution of basic aluminum sulfate. Steam regeneration of the aluminum sulfate solution drives off essentially pure SO_2. This process again is only applicable to high concentrations of SO_2 (at least one percent).

Chemical Regenerative Sulfur Dioxide Removal Processes

Sodium Sulfite-Zinc Sulfite Process The gas stream is brought in contact with sodium sulfite, yielding sodium bisulfite which reforms sodium sulfite and produces zinc sulfite when the bisulfite is treated with zinc oxides. Zinc sulfite is then calcined to drive off pure SO_2 and reform zinc oxide. This treatment yields nearly complete removal of SO_2 but is not economical below 0.5 percent SO_2. In addition to SO_2,the process creates a calcium sulfate residue which is usually disposed to the land.

Non-Regenerative Sulfur Dioxide Removal Processes

Ammonia-Sulfuric Acid Process This is essentially the same as the regenerative ammonia process (ammonia sulfite and ammonium bisulfate contacted countercurrently with SO_2). The effluent solution is treated with sulfuric acid forming ammonium sulfate and SO_2, both of which are dried and reclaimed. Essentially complete removal of SO_2 with as little as 0.1 percent SO_2 initial concentration is achieved. Also the sulfate produced is in marketable form.

Lime-Neutralization Process The SO_2 is absorbed by water containing calcium hydroxide, calcium sulfite, and calcium sulfate. The SO_2 reacts with calcium hydroxide to form calcium sulfite. Oxygen in stack gases also dissolves in water and reacts with calcium sulfite to form calcium sulfate. This affords essentially complete removal of SO_2 and is best suited to low initial concentrations of SO_2. The calcium sulfate (gypsum) which is produced is usable in wallboard production.

Absorption by Alkaline Water Alkaline water is used to absorb the SO_2, the acidic SO_2 being neutralized. If enough water is used, nearly complete removal of SO_2 is possible. The process works best on low SO_2 concentrations. Large quantities of water are needed and care is required in handling the effluent,or receiving waters may be polluted. The effluent from this process contains sulfates, with calcium, magnesium and other compounds.

Catalytic Oxidation to Sulfuric Acid In this process SO_2 and O_2 are absorbed by plain water. These react to form dilute sulfuric acid. Small quantities of iron or manganese promote oxidation. This process is effective at relatively low concentrations of SO_2,and nearly complete removal is possible. This process produces dilute sulfuric acid which, except under special circumstances, cannot be economically concentrated to commercial strength.

Sulfur Compound Removal from Water A number of treatment process which are in use today may remove sulfide compounds in water with varying effectiveness. Activated carbon adsorption (80-99 percent), chemical coagulation (14-50 percent), trickling filters (75-100 percent), and activated sludge (75-100 percent)[73] are common treatment systems used for different sources. All these processes generate ultimate residues which require disposal to another medium,and some may produce hydrogen sulfide which may enter the atmosphere directly from aqueous media. Treatment methods will be further discussed in the Summary of Controls, Section VI.

NITROGEN OXIDES AND COMPOUNDS

Intermedia Relationships

Intermedia transport of nitrogen compounds in nature has been deduced quantitatively by Robinson and Robbins.[107] Intermedia flows of nitrogen compounds artificially produced are shown in Figures 6 and 7. Man-controlled transfers of these compounds between the fluid media are few and inefficient: incineration of nitrogenous sludges is an effective mode of transfer to air of compounds in which nitrogen is in a highly reduced state (as ammonia), but ineffective for nitrites and nitrates; and nitrogen oxides are not efficiently scrubbed from exhaust stacks. As a result of man's inability efficiently to effect intermedia transfer of nitrogen compounds, the important control methods for abatement of nitrogen-compound pollution are process-centered rather than treatment-centered and are distinctly non-intermedial in character.

Environmental Impact

Nitrogen oxides react quickly with hydrocarbons in the presence of sunlight to form organic-nitrogen compounds, such that both the direct effects of the oxides and the indirect effects of their photo-chemical products (such as peroxyacetyl nitrate, i.e. PAN) must be considered. Nitrogen oxides are significant as air pollutants because they are potential health hazards in many industries. For purposes of comparison, nitrogen dioxide is more toxic than carbon monoxide at equal concentrations.[5]

Specific evidence of a deleterious effect on human health of atmospheric NO_x is limited, although many deaths were reported from poisoning by this substance in a bizarre fire in 1924.[74] Air pollution concentrations of the substance may be related to chronic pulmonary fibrosis.[59] Plant life may be injured by substantial NO_2 concentrations of approximately 25 ppm found near nitric acid plants, but general community air pollution levels of NO_2 are probably not significant enough to cause plant damage.[5] PAN and its related compounds possess toxicities comparable to NO_2,[3] although the toxicity of the former is appreciably temperature dependent.[75] It also appears to be a significant eye irritant[76] and is more harmful than NO_2 in that it attacks all forms of vegetation, causing discoloration, blotching, needle blight, etc. at concentrations down to .01-.05 ppm for sensitive plants.[61]

Corrosion of materials can occur as a result of reactions with atmospheric nitric acid, from NO_2 via N_2O_5 and water.[5] A unique effect of atmospheric NO_2 is sky discoloration. Due to its absorption in the blue-green region of the spectrum, NO_2 imparts a brownish-red color to the atmosphere, thus creating a visible smog.

In bodies of water, the effects of nitrogen may encourage rapid eutrophication, and aid the development of sludge deposits. A high nitrogen concentration serves as a nutrient building material for algae. As the algae grow, they use nutrients in the water until the nutrients are consumed. When the algae begin to die, bacteria decompose the organic material, using up the dissolved oxygen in the water and creating the same

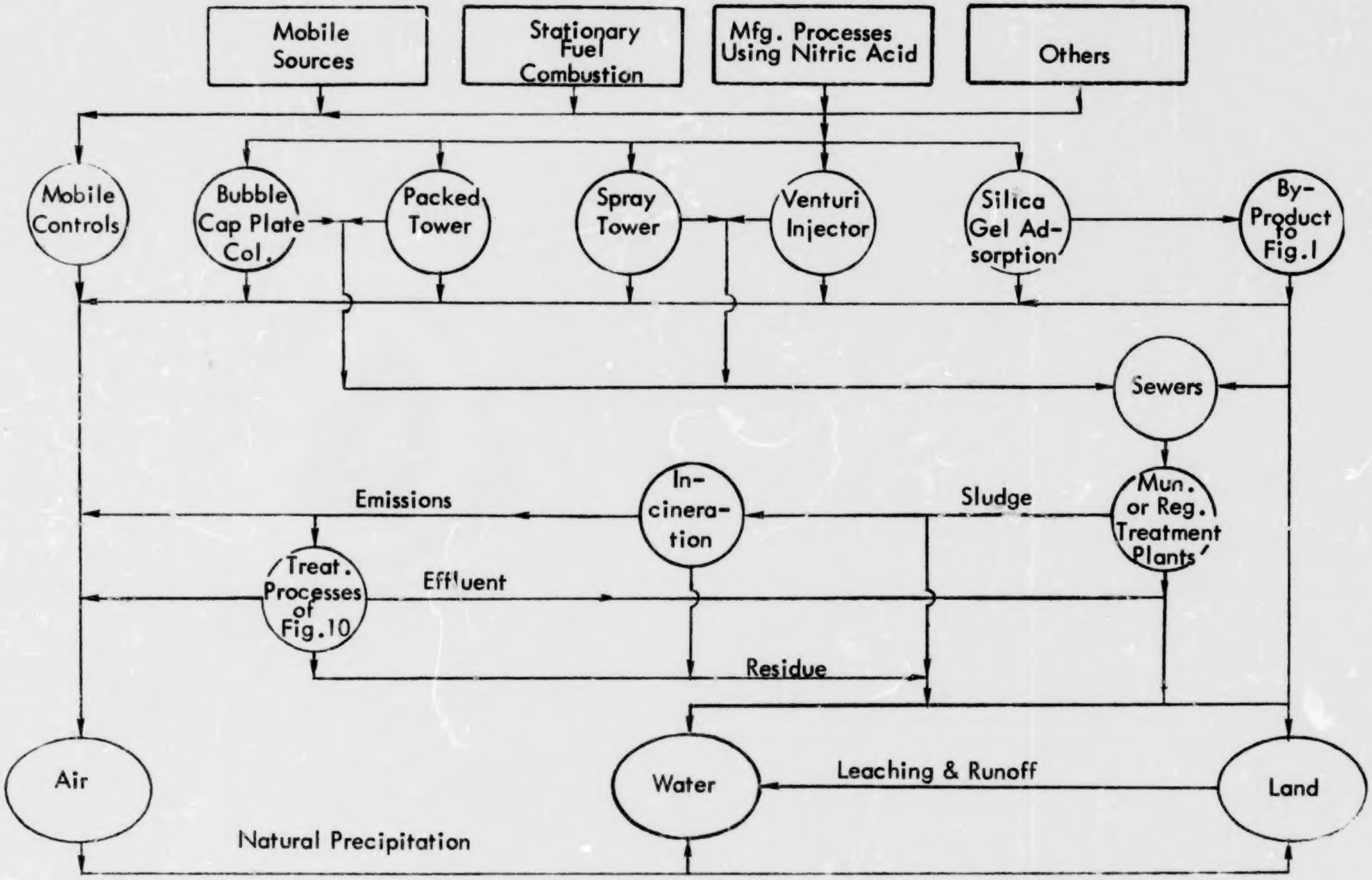

Mobile Sources
Stationary Fuel Combustion
Mfg. Processes Using Nitric Acid
Others
Mobile Controls
Bubble Cap Plate Col.
Packed Tower
Spray Tower
Venturi Injector
Silica Gel Adsorption
By-Product to Fig.1
Sewers
Emissions
In-cineration
Sludge
Mun. or Reg. Treatment Plants
Treat. Processes of Fig.10
Effluent
Residue
Air
Water
Leaching & Runoff
Land
Natural Precipitation

FIGURE 6
INTERMEDIA FLOW CHART
NITROGEN OXIDES

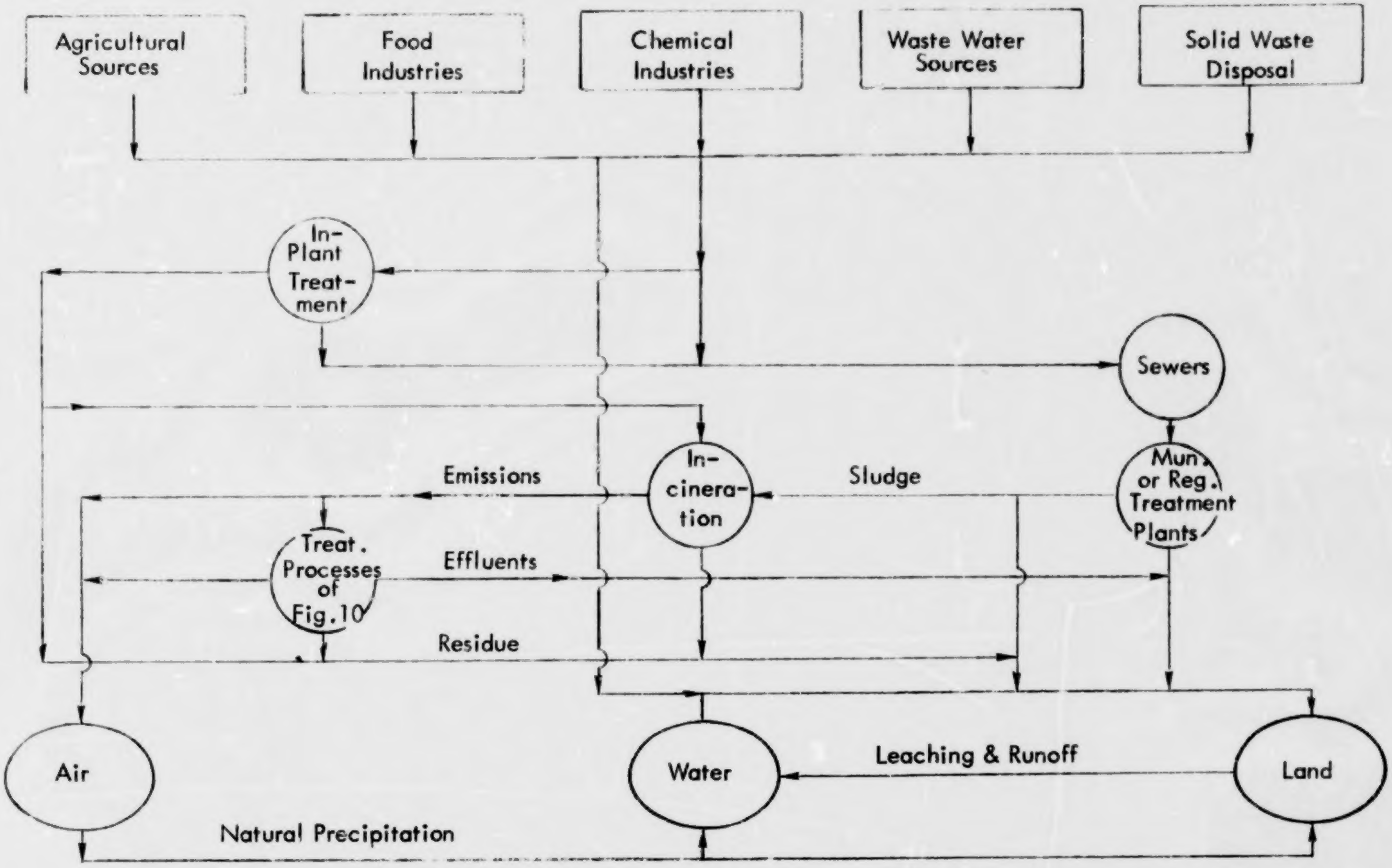

Agricultural Sources
Food Industries
Chemical Industries
Waste Water Sources
Solid Waste Disposal
In-Plant Treat-ment
Sewers
In-cinera-tion
Mun. or Reg. Treatment Plants
Emissions
Sludge
Treat. Processes of Fig.10
Effluents
Residue
Air
Water
Land
Leaching & Runoff
Natural Precipitation

FIGURE 7
INTERMEDIA FLOW CHART
NITROGEN COMPOUNDS

problems discussed under BOD impact leter in this section. The large amounts of living and dead algae which result from the nitrogen compounds cause turbidity, disagreeable color, taste, and odor, sludge solids deposition, and other nuisances. The cost of removal of the nitrogen nutrient must be viewed in terms of the alternate uses of the receiving waters.[70] Ammonia, nitrates, nitrites and organic nitrogen are common nutrients.

Main Sources

Estimated total emissions for 1970 of nitrogen oxides (NO_x) were 22.7×10^6 tons,[14] nearly all of which was produced from mobile and stationary fuel combustion sources. A significant variation in emission factors occurs, depending on the specific combustion method. It should be emphasized that in fuel combustion NO_x is produced not from nitrogenous fuel components, but from reaction between the oxygen and nitrogen in the combustion air at the high temperatures (greater than 1200°F). The yield of NO_x increases (under equilibrium conditions) with increasing temperature.[77]

Found in water, nitrogen and its compounds, particularly ammonia, are formed as the undesirable by-products of such industries as agricultural production,[79, 114, 128] food and kindred products,[78] chemicals and allied products[65] and sanitary services.[79]

Treatment and Controls

Alternative Processes - Airborne emissions Process-oriented abatement of NO_x emissions from stationary combustion sources is centered around minimization of both the combustion temperature and the air-to-fuel ratio, but air-to-fuel ratios which minimize NO_x emissions tend to maximize unburned hydrocarbon emissions.

Two-stage combustion in power-plant boilers is singularly effective in reducing NO_x emissions.

Bubble-cap Plate Columns Nitrogen oxides can be removed by passing the gas stream through a series of bubble-cap plates countercurrent to the flow of water or aqueous nitric acid. For the low concentrations of NO_x usually found in stack gases, bubble-cap columns are very inefficient.

Venturi Injector In this process, water is sprayed axially into a high velocity flow of gas through a venturi throat. The large amount of interfacial area between the gas and atomized liquid gives high rates of absorption of the oxides. If steam is added to the entering gases, the increased water-vapor pressure tends to promote the gas-phase reactions and increase the efficiency of removal of oxides of nitrogen. The effluent gases must be treated with a cyclone or other separating equipment to remove the nitric acid mist which is formed by the process.

Packed Towers and Spray Towers These processes, used with countercurrent water and gas flow, can remove oxides of nitrogen. At low concentration, these processes give low efficiencies.

Adsorption on Silica Gel In gas streams containing 1 to 1.5 percent nitric oxide the latter may be removed by oxidizing it to nitrogen dioxide which is then adsorbed out of the gas stream onto silica gel. The nitric oxide oxidation can be catalyzed by silica gel containing nitrogen dioxide. Heating the silica gel releases the adsorbed gas.

Mobile Source Control The concentration of nitrogen oxides in mobile exhausts is most heavily influenced by peak combustion temperatures and by oxygen availability at the combustion temperature. Reduction in either of these variables reduces NO_x emissions and their effects are additive. However, the best air-fuel mixture for the control of carbon monoxide and hydrocarbon, which is about 15 pounds of air per pound of fuel (15:1) is near the optimum level for the production of NO_x. Conversely, the best air-fuel ratio for reduction of NO_x, near 12:1, produces a disastrous 3 percent carbon monoxide in the exhaust emissions.[321]

One method of control for NO_x is the introduction of exhaust gas into the cylinder intake charge. This reduces both temperature and oxygen concentration, and yields up to a 90 percent reduction in NO_x. This method, however, adversely affects carbon monoxide control. Copper catalysts have been used to reduce NO_x but also require conditions adverse to other emission-control objectives.[321]

Treatment Efficiencies

If the stack gases contain less than 1.0 percent oxides of nitrogen, bubble-cap, packed, and spray towers have very poor efficiencies. The silica gel process has large initial costs and the gel is easily fouled by other ordinary gases containing dust, moisture, and other materials. This process has the advantage of recovering nitrogen oxides in a concentrated form which can be used for making nitric acid. The venturi injector is probably the most economic method for NO_x removal. For higher efficiencies more units can be added in series.[18]

HEAVY METALS

Intermedia Relationships

Figure 8 depicts the intermedia relationships for both water-and airborne heavy metal discharges, with the exception of lead, which mainly originates from mobile exhausts. Most heavy metal discharges and emissions can be controlled by methods having intermedia implications.

For airborne emissions both dry (precipitators, etc.) and wet (water scrubbing, etc.) removal processes can be used. The dry processes may use either a dry process or a water flush to remove the residues. In the latter case, the wash water produces the same problems as the effluent from a scrubber. The residue from dry processes may be incinerated if other combustible materials have been removed along with the heavy metals. Otherwise, they may go directly to land disposal or may be recycled. Recycling is a possibility for both water and air discharges since some heavy metals have a high recovery valve.

Heavy metals in water from either removal processes or primary industrial sources may be either soluble or in a suspended state. Removal of solubles is accomplished by physical-chemical methods, while suspended solids may be removed by either physical or physical-chemical methods.

The alternatives for sludge disposal are the same as those discussed for phosphorous compounds. The sludge may be incinerated or may be discharged to receiving water or to the land. Incinerator emissions may be further treated as shown in Figure 9 . Heavy metals may then leach from landfills or be carried by runoff from the land. Most heavy metals precipitate fairly rapidly from the air to water or land and, as with phosphorus compounds, do not transfer readily to the air upon incineration, but tend to remain in the slag or ash.

Environmental Impact

Heavy metals occur naturally in the environment as part of the earth's crust. Many industrial processes produce pollutants containing heavy metals in various forms which, depending on the dosage received, may be toxic to wildlife, micro-organisms and human life. Concentration in the food chain presents increasing hazards to the higher life forms.

Once heavy metals are discharged to the environment, intermedia transfer of the pollutants is possible. Contaminants entering the atmosphere can, after a period of time, settle to the land and water through natural fallout and rainfall. Heavy metal wastes applied to the land and metals settling on land through atmospheric fallout, can further contaminate local surface waters through storm runoff and continental weathering.

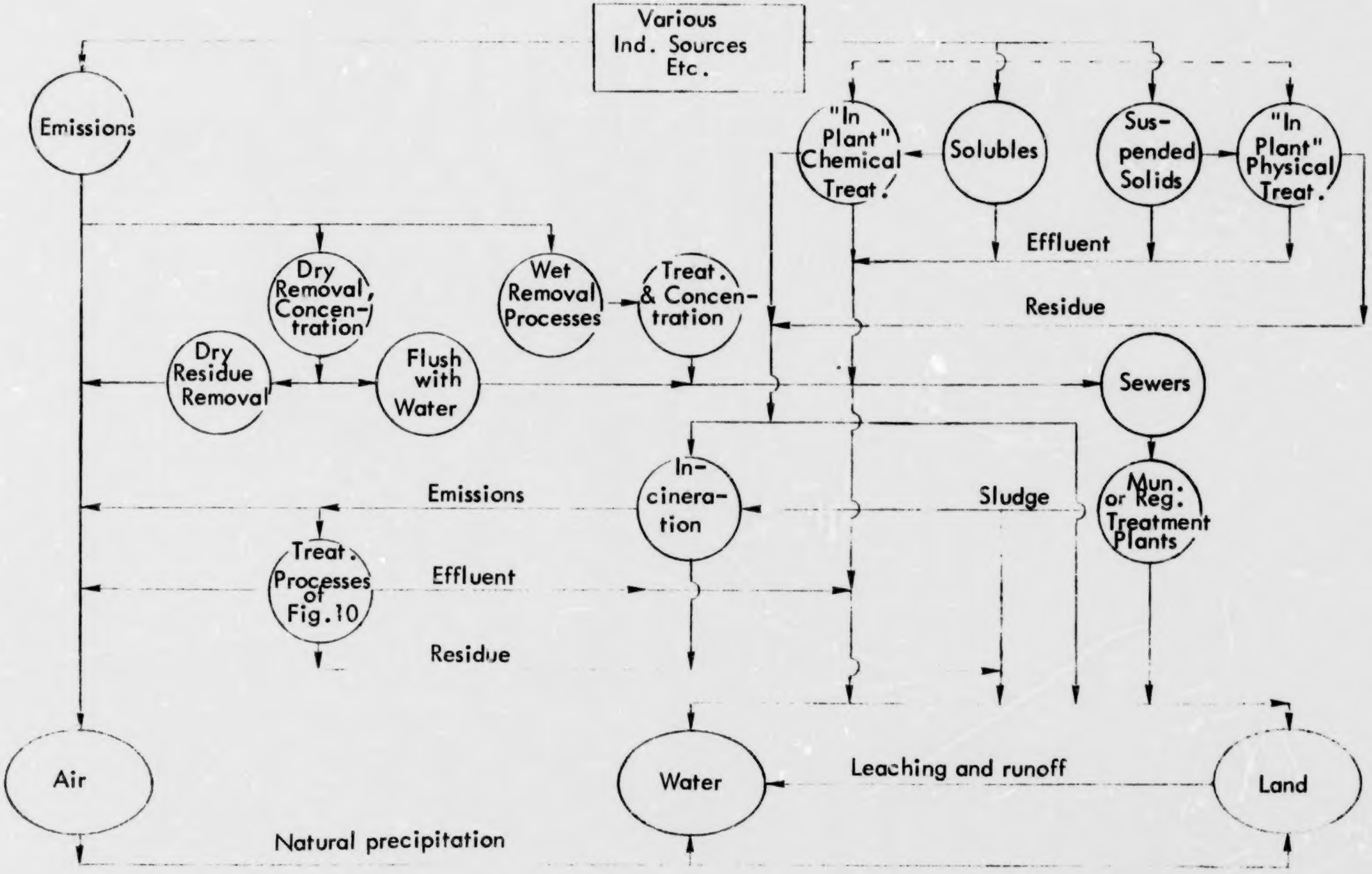

Various
Ind. Sources
Etc.
Emissions
"In Plant" Chemical Treat.
Solubles
Sus-pended Solids
"In Plant" Physical Treat.
Effluent
Residue
Dry Removal, Concen-tration
Wet Removal Processes
Treat. & Concen-tration
Dry Residue Removal
Flush with Water
Sewers
In-cinera-tion
Mun. or Reg. Treatment Plants
Emissions
Sludge
Treat. Processes of Fig.10
Effluent
Residue
Air
Water
Leaching and runoff
Land
Natural precipitation

FIGURE 8
INTERMEDIA FLOW CHART
HEAVY METALS

The heavy metals considered here are lead, mercury, cadmium, and nickel. Quantitative data do exist concerning the intermedia transfer of a few of these metals.

Main Sources

Mercury Mercury is widely used in industry and agriculture. The major applications are in the manufacture of electrical apparatus, the electrolytic preparation of chlorine and caustic soda, and in the preparation of fungicides, herbicides, pesticides and explosives. About 26 percent of the six million pounds of mercury consumed per year is used for the electrolytic preparation of chlorine and soda. The second major consumer of mercury is the electrical equipment industry which uses approximately 23.5 percent of the total.[130]

There is a natural interemedia transfer of mercury in the environment which is increased because of the additional mercury contributed by industrial processes. Mercury can enter the atmosphere in both the gaseous and particulate forms. Its mobility is enhanced by its physical properties, which are unique among metals. As a metallic liquid its vapor pressure is relatively high for a metal and makes possible natural land to air transfer.

Gaseous and particulate mercury compounds are commonly contained in the emissions from various industrial processes. Mercury has been found in 36 United States' coals. A conservative estimate of the average mercury concentration in all United States' coals is around 1 mg/l. Approximately 2 billion tons of coal are burned annually in the United States, resulting in a release of 3,000 tons of mercury to the environment.[131] Mercury vapor discharges from some coal burning power plants, municipal incinerators, and several types of industrial plants may range from 100 to 5,400 pounds per year at individual sites. The estimated annual rate of mercury vapor discharge from 12 locations in Missouri and Illinois exceeds the rate of mercury discharge into waterways by the nation's 50 major mercury polluters.[134] Mercury vapors can also escape to the atmosphere as dust from open pit mining.[135]

Mercury is continually being removed from the atmosphere and deposited on the earth's surface. Estimates of the input rate of mercury from the atmosphere to the entire global surface from fallout are between 5.50×10^7 and 9.68×10^8 pounds per year.[136] The fallout is expected to be higher in the more industrial areas.

About 5,000 tons of mercury per year are released to rivers by continental weathering.[137] Mine drainage contributes significant amounts of mercury to streams. Soluble mercury introduced into streams is rapidly reduced to its metallic mercury form by various natural chemical processes.[138] Approximately 8,800 pounds per year of mercury is discharged into Southern California coastal waters via sewage effluents. The average mercury concentration of the effluent is .003 mg/l. Localized mercury inputs from sewage outfalls result in mercury concentrations near the outfalls which are

50 times larger than natural concentrations. Ocean sediment samples collected near Los Angeles sewage outfalls contained about 1 mg/l mercury on a dry weight basis as compared to a control area concentration of .02 mg/l.[139]

No attempt has yet been made to study air-water interactions of mercury, but this mode of transfer has potential significance.[135]

Lead Lead is another heavy metal very commonly discharged in industrial wastes. The uses of lead include the production of storage batteries, cables, paint pigments and ammunition. The annual consumption of lead in the United States is one million tons.

About 20 percent of the lead consumed is used for lead alkyls which are the anti-knock ingredients in gasolines. Combustion of leaded gasoline is the major source of lead in the atmosphere; about 300,000 tons are added directly to the air annually.[140] This results in an average lead concentration of 0.6 micrograms per cubic meter in urban atmosphere near ground level[141] while in Los Angeles the atmospheric lead concentration is 5 micrograms per cubic meter.[40] The combustion of lead alkyls in gasoline produces aerosol forms of inorganic lead salts such as lead chlorobromide. After emission, lead quickly becomes diluted in the atmosphere and it has been found that about 1,300 feet downwind from a freeway, the average lead concentration reduces to 22 percent of the roadside value[142].

Lead aerosols are thought to have a settling half-life of about three hours in urban atmospheres.[141] In rural areas it has been estimated that the quantity of lead fallout is 26,400 tons per year.[141]

Rivers can be contaminated with lead alkyls from atmospheric fallout. The major pathway by which lead alkyls reach surface waters in urban areas probably, is by the discharge from storm sewers. About two-thirds of the urban fallout of lead alkyls, which are soluble salts, find their way into storm sewers. Such lead contributions amount to about 8,800 tons per year. The majority of this comes from automotive exhausts.

Surface waters can become contaminated directly from lead fallout. The seepage of lead wastes from scrap heaps and the weathering products of lead paints all contribute lead to surface waters.[141]

Cadmium Cadmium is closely related chemically to zinc, and is found with zinc ores in nature. It is obtained as a by-product in the refining of zinc and other metals. Cadmium is emitted to the air and water in mining processes and from metal smelters, especially lead, copper and zinc smelters. Also, industries using cadmium in alloys, paints, and plastics produce cadmium wastes. The burning of oil and scrap metal treatment wastes also contribute to the amount of cadmium entering the air. Cadmium which is emitted to the air is ultimately deposited on the soil and water.

High concentrations of cadmium have been found in sewage treatment plant sludges. Soil contamination is possible when these sludges are used as fertilizers.[143] Plants are capable of extracting cadmium from soil and when consumed can be toxic to man and animals.[144] Certain fertilizers contain cadmium, and the chief route by which cadmium reaches man is believed to be through food grown in soils containing cadmium derived from super-phosphate fertilizers.

Nickel Nickel has many industrial applications, but nickel alloys used in many food-processing operations are considered to be the major sources of nickel in water and soil and which ultimately reach man. Nickel carbonyl is considered to be the most serious environmental hazard of all the nickel compounds studied. Nickel carbonyl is formed when inorganic nickel in the air reacts with carbon monoxide. The use of nickel based gasoline additives such as nickel isodecylorthophosphate should, therefore, be discouraged.[146,147]

Controls

The principal methods of control of heavy metals in discharges and emissions are pretreatment and the restricted use of heavy metals where substitution can be made. Examples are the elimination of mercury seals in trickling filters, a long standing practice; the restrictions on pesticides containing mercury compounds; and the reduced use of lead-base paints.

Treatment Methods

The intermedial flows and controls for heavy metals are represented in Figure 8 Several methods have been employed by industry to remove heavy metals from their discharges. For waterborne wastes, physical separation is used to remove suspended solids from effluents, while chemical or biological methods are employed to extract the soluble components. The sludges generated may be dewatered before the ultimate disposal to the land. Heavy metals may appear in industrial discharges to the atmosphere and control measures such as gas scrubbers and electrostatic precipitators may be applied.

Sludges placed to landfills can possibly contaminate underground water, although this is not likely to occur if the landfill is adequately designed and constructed. The available treatment cost information is presented in Table VI.

RADIOACTIVE WASTES

Intermedial Relationships

Figure 9 illustrates the intermedial relationships for radioactive wastes. This is definitely an intermedial pollutant and is rapidly becoming a national problem. In the fission process, by which nuclear reactors produce energy, both liquid and gaseous wastes are created. The two main sources of these wastes are from the spent fuels and from leaks into the primary cooling water.

Radioactive gas wastes require continual removal from the primary coolant and are then normally stored temporarily on a batch basis to reduce radioactivity before release to the atmosphere.

Several in-plant treatments can be employed to remove radioactivity from liquid waste effluents. These treatments result in the radioactivity being low in the treated effluent and fairly high in the treatment residues. The treated effluents can then be discharged into local sewers or adjacent waterways while the residues can be incinerated if the radioactivity level is below a certain level. The various levels which have been established will be discussed later. Incinerator emissions can be controlled as shown in Figure 9. If the level of radioactivity is above that established as a limit for incineration, the residues may be sealed in containers for burial in specified locations.

The reprocessing of spent uranium fuel elements results in liquid wastes of high radioactivity. These wastes are usually permanently stored underground, in salt caves, or at sea. An alternative to direct liquid waste disposal is the transformation of highly radioactive liquid wastes to solid wastes by calcination. These solid wastes can be incorporated into a vitrified solid mass containing ferrous and glass aggregates prior to ultimate disposal underground or to the sea. Such adulteration enhances the heat-rejecting capability of the resulting solid mass. Radioactive residues applied to the land can be transmitted to adjacent waters by leaching and runoff. Radioactive exhaust emissions from nuclear reactors and incinerators can return to water and land by natural fallout and precipitation.

Environmental Impact

All radioactive wastes discharged to the environment should be evaluated in terms of their potential contribution to radiation exposure of the surrounding community so that the total radiation dose from the waste and from existing radiation sources can be determined. Radiation wastes may be classified quantitatively as (1) low-level, if the activity can be measured in microcuries per liter or per gallon; (2) intermediate-level, if the activity is measured in millicuries per liter or per gallon; and (3) high-level, if the activity is measured in curies per liter or per gallon. These criteria for measuring

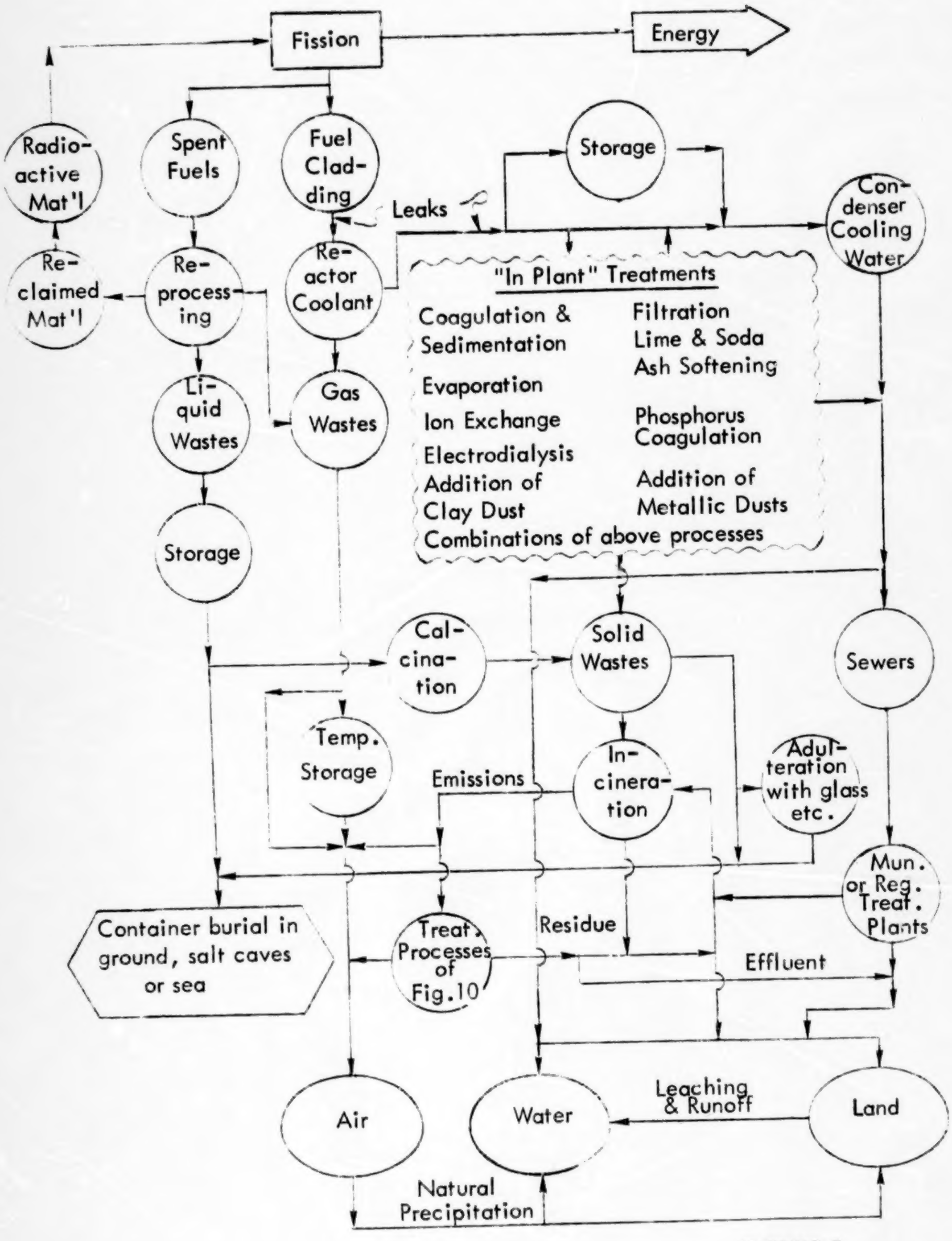

Fission
Energy
Radio-active Mat'l
Spent Fuels
Fuel Clad-ding
Storage
Leaks
Con-denser Cooling Water
Re-claimed Mat'l
Re-process-ing
Re-actor Coolant
"In Plant" Treatments
Coagulation & Sedimentation
Filtration
Lime & Soda Ash Softening
Evaporation
Ion Exchange
Phosphorus Coagulation
Electrodialysis
Addition of Clay Dust
Addition of Metallic Dusts
Combinations of above processes
Li-quid Wastes
Gas Wastes
Storage
Cal-cina-tion
Solid Wastes
Sewers
Temp. Storage
Emissions
In-cinera-tion
Adul-teration with glass etc.
Mun. or Reg. Treat. Plants
Container burial in ground, salt caves or sea
Treat. Processes of Fig.10
Residue
Effluent
Air
Water
Leaching & Runoff
Land
Natural Precipitation

FIGURE 9
INTERMEDIA FLOW CHART
RADIOACTIVE MATERIALS

radioactive wastes are very simple, but not completely adequate, because the radiotoxicity of various isotopes in nuclear waste is not considered. Radionuclides contained in the water must first be identified before knowledge of the radiotoxicity can be acquired. The radiotoxicity of specific nuclides may be obtained by referring to the MPC (maximum permissible concentration) values for air and water recommended by the International Commission on Radiation Protection (ICRP)[148] and by the National Committee on Radiation Protection (NCRP).[149]

When assessing the possible effects of environmental radioactivity on living matter, it is important to ascertain: (1) the population affected by a particular isotope, (2) the toxicity of the isotope, (3) the organs within the specie affected by the isotope, and (4) the mechanism of exposure to the isotope. For example, in sufficient doses I 131 is harmful (toxicity) to the thyroid gland (target organ) of man (population). The isotope I 131 is commonly used in medical research (exposure mechanism).

The sources of radioactivity in the environment are the fallout from nuclear testing and the discharge or disposal of radioactive wastes from nuclear power plants and other research facilities. The main radionuclides of concern are Sr 90, Cs 137 and I 131. Artificial radioactivity is present in natural waters mainly because of controlled waste disposal into rivers and lakes. Radioactivity can also contaminate surface waters from wastes released to the atmosphere or to the ground. Another source of radioactivity affects a limited population living adjacent to uranium mines where contaminated water is discharged after being used for milling and from tailings. Water containing radioactivity can result in the exposure of people using the water for drinking, working, and recreational purposes. Exposure can also occur if contaminated water is used to irrigate plants or by the radioactive pollution of an aquatic environment used for cultivating marine life for human consumption. If radioactive wastes are discharged into the ocean, biological accumulation of radionuclides can result in considerable contamination of marine organisms.

Main Source

When fuel is fissioned in a nuclear reactor to sustain a chain reaction, large quantities of radioactivity and heat are created. Approximately 2.68×10^4 curies of radioactivity are formed for each megawatt of thermal power.[151] Since the conversion of thermal power to electrical power is only about thirty-three percent efficient, about 8×10^4 curies of radioactivity are formed for each megawatt of electrical power. Fission products from the fuel are usually contained within a metal-clad solid matrix, but occasionally tiny pinhole leaks or fractures develop in the cladding and certain fission products are released to the reactor coolant. In general, before discharge to the environment, radioactive materials produced in reactor fuels must pass through several barriers which have large retention factors. The first is the solid matrix where the fission products are usually formed; second is the cladding of the fuel element; third is the coolant and its confinement system; and the last is the containment vessel of the power reactor.

Of public health concern are the long-lived nuclides such as Sr 90 and Ce 137 which are fission products. Some of the other fission products are gases and include radioactive isotopes of iodine, krypton, and xenon.

Controls

Figure 9 illustrates the pollution source points and controls possible in nuclear power plants as well as the intermedia flows.

Three concepts of radioactive waste handling are widely used in industrial activities:

Dilute and Disperse Typical of this method is the dispersion of radioactive gases for dilution in the atmosphere and the controlled release of radioactive liquids into surface waterways.

Concentrate and Contain This method applies to the concentration and containment of nuclear fuel reprocessing wastes, evaporator residues, and incinerator solids.

Delay and Decay The radioactivity of an element is lost only through decay. Temporary retention of short-lived radionuclides results in sufficiently low levels of radioactivity which may be released to the environment. An application of the delay and decay concept has found use in the introduction of radioactive material into selected soils, where slow groundwater movement and the opportunity for the exchange of radioactive ions in solution with soil cations provide the delay necessary for decay.

Low- and intermediate-level wastes are released to the environment. The major practice in the treatment and handling of high-level wastes consists of underground tank storage with no direct release to the environment. Other methods of handling high-level radioactive wastes are being studied which may supersede tank storage. These methods include calcination, incorporation of glass, deep-well disposal, and salt-dome disposal.[151]

Liquid Wastes

Liquid wastes from nuclear power plants may contain radioactive materials from laboratory drains, laundry facilities, and floor drain systems that receive small amounts of leakage from pump seals and other sources. Liquid wastes are usually collected in storage tanks and are released to the environment on a batch basis after the batch has been monitored to assure low radioactivity. The waste batch is subjected to "in plant" treatments before release to the condenser cooling water and receiving waters.

Gaseous Wastes

Gaseous wastes include isotopes of iodine and other halogens and noble gases such as krypton and xenon. These gases must be continuously removed from the primary cooling water to prevent accumulation and undesirable radiation levels. In pressurized water reactors, waste gas quantities are small, and the gases are delivered to storage tanks and contained for 30 days or more. During this time period radioactive decay reduces the radioactivity of the gases to low levels before they are released to the plant stack for dilution and dispersion to the atmosphere. Boiling water reactors produce larger volumes of gaseous wastes; therefore, the detention time for radioactive decay before release must be much shorter, about 30 minutes. This results in larger quantities of radioactivity released via the plant stack.

Fuel Reprocessing Wastes

After use, spent fuel rods from nuclear reactors are sent to a plant where the remaining uranium is reclaimed and repurified. Most of the radioactive fission products are contained in the spent fuel rods, and the radioactivity of these products is very high. In reprocessing, the fuel is dissolved in acids, and the uranium is then reclaimed by chemical reprocessing. All the fission products are wastes, and these large quantities of high radioactivity are delivered to underground storage tanks for long term containment and decay. Heat generated by the radioactivity causes these wastes to boil for periods up to 2 years in the storage tanks. The gaseous wastes are released to the atmosphere. It is estimated that a single fuel reprocessing facility planned in South Carolina may release from its stack as much as 12 million curies per year of Kr 85 and 500,000 curies per year of tritium.[152]

The Removal of Radioactivity

Water Treatment.

An evaluation of water treatment processes is of concern because much of the liquid waste of low radioactivity is discharged either directly or through sewage systems to water environments. Many communities use rivers and wells as a source of water supply and utilize some form of water treatment prior to use. It is important to understand the effectiveness of conventional water treatment processes in terms of removal capability of radioactive materials. The conventional methods of water treatment include chemical coagulation and sedimentation, filtration, lime and soda-ash softening and ion exchange.

Chemical coagulation involves the destabilization, aggregation, and binding together of colloids. These colloids form chemical flocs that adsorb, entrap, or otherwise concentrate suspended matter.[153] Common coagulants are alum and iron salts which precipitate soluble components in the water as aluminum and iron hydroxides. Coagulation is ineffective as a method of removing soluble radioactive materials, with the exception of most of those cations with valences 3, 4, or 5, including the rare earth group. Coagulation is considerably more effective in removing particulate-associated radioactivity characteristic of the turbidity usually found in surface waters.

Sedimentation is the process by which suspended particles, heavier than water, are removed by gravitational settling. It usually precedes filtration, with or without coagulation.

Filtration is accomplished by the passage of water through granular materials. Sand filters have not been directly effective in removing radioactive materials.[154, 155] Their major function is to remove the radioactivity previously incorporated in floc or other filterable particles.

Water is softened by the addition of lime which removes carbonate hardness, or by soda ash which removes non-carbonate hardness. Reasonable amounts of softening chemical will provide 90 percent or better removal of soluble Ba 140, La 140, Sr 89, Cd 115, Sc 46, Y 91, and Zr 95, Nb 95, but larger quantities of the chemical are ineffective against removals of Cs 137, Ba 137 and W 185.[154] Treatment with lime and soda ash finds its greatest use in the removal of potentially hazardous strontium.

Ion exchange involves an exchange of certain ions during the passage of water through a bed of resin. When the resin bed is exhausted, it is regenerated with brine of other treatment. Ion exchange has been used most successfully for the removal of small amounts of radioactive ions from very dilute pollutions. Other applications of ion exchange will be discussed later in this report.

There are several methods for the removal of radioactive constituents from water which differ from the conventional processes. These nonconventional processes include phosphate coagulation, electrodialysis with permselective membranes, and the addition of metallic dusts and clay materials. Phosphate coagulation has been shown to be superior to the usual alum or iron-salt coagulation for the removal of radioactive materials.[156] Phosphate coagulation is used for the removal of radioactivity since many polyvalent cations form relatively insoluble phosphate compounds, and because phosphate floc can be formed in a solution at high pH. The removal of specific soluble radioactive contaminants by slurrying various metal dusts in the solution has been studied.[157] The addition of small amounts of clay (100 mg/liter) to a solution can remove radionuclides by coagulation and sedimentation.[158, 159, 160, 161]

Biological Treatment The practice of discharging to sewers and subsequent treatment in municipal or regional plants has encouraged the study of the efficiencies of the various processes for removing radioactive materials from wastewater. Since the radioactivity of a material can be reduced only through decay, these materials must be removed with the organic and inorganic solids. After additional processing, some sludges may be used as fertilizers. If long-lived high-energy radionuclides are included, a public health hazard may exist from the use of these fertilizers.

Biological treatment processes have been shown to be rather inefficient for the removal of radioactive materials from water.[150] Trickling filters appear to be more satisfactory for waste decontamination than either the activated sludge process or oxidation ponds. Complexing or chelating agents markedly interfere with biological processes and must be neutralized or removed before biological treatment.[163, 164]

Evaporation and Storage Large quantities of radioactive wastes are evaporated when direct discharge to the environment is to be avoided and when decontamination factors between 10^2 and 10^6 are required. Evaporation is expensive but storage is an even more costly alternative which is used only as a temporary measure for the decay of very short-lived radionuclides. When decontamination factors are not too stringent (less than 10^2) precipitation, rather than evaporation, should be considered for decontamination. Ion-exchange resins are applicable to wastes with low salt content, while the solvent extract method may be applicable to wastes of higher salt concentrations.[150]

Electrodialysis, Solvent Extraction and Other Methods The goal of these methods is the concentration of the radionuclides into a small volume which can be readily controlled. Electrodialysis, solvent extraction, crystallization, and foam separation have specific applications in particular areas. None of these processes is being utilized on a large scale for radioactive waste treatment, but all have been studied in the laboratory, and some on a pilot plant level. Large scale applications of these methods require further study and refinement because they are not yet economically competitive with other treatment processes.[150]

Solid Waste Disposal Combustible wastes can be reduced in volume by baling, incineration in special equipment, or by burning in the open. Volume reductions from 1.7:1 up to 10:1 have been reported for baling. Volume reductions by incineration of 3 to 21 times those reported for baling have been attained.[168] Noncombustible wastes generally cannot be significantly reduced in volume.

There are five disposal sites in the United States, all under AEC control. Before a site can be selected for burial of solid radioactive wastes, the geology of the area must be studied for structure, texture, composition, and the ion-exchange capacity of the soil. Data are also needed on the rate of release of radioactivity from the burial area, the elevation of the groundwater table, and the distance of downstream users of groundwater.

Land burial is the cheapest method of handling solid wastes. Ocean disposal of packaged material is much more expensive due to high costs of special containers, transportation to the dock, and transportation to the disposal point in the ocean.[150]

A solid waste solution to the long range problem of high activity nuclear waste disposal has been proposed. The vast quantities generated are currently stored in tanks which must be replaced after 10 to 20 years because of the corrosiveness of the stored material. The high-level radioactive materials must be stored for hundreds of years, until the nuclear materials decay.

The proposed solution involves converting the high-level radioactive wastes into a solid inert form. The nuclear waste can be mixed with metal and glass and the composite encapsulated in a massive metal container. Research has demonstrated that liquid wastes can be converted into radioactive solids of much smaller volume by calcining. However, to store the waste, these solids need containerization and continuous cooling. The low thermal conductivity of the calcined radioactive waste can be improved significantly if the calcined product is mixed with glass or metal powders. These composites can then be formed into blocks in which the improved thermal conductivity permits the heat generated to be dissipated without additional cooling. The composite blocks must be containerized in a shielding material of high thermal conductivity to prevent interaction between the radioactive wastes and the environment.

High temperature incineration of municipal refuse produces glass and metal which, without further processing, is suitable for both compositing and containing the high-level solid waste. Although glass, ferrous and non-ferrous metal granules are effective for the matrix, only ferrous material can be used for the container.

Once formed, the container would be resistant to radiolytic damage and would permit mechanical handling. Radioactive waste in this form can then be stored in abandoned salt mines.

MAJOR INTERMEDIA AIR POLLUTANT (SINGLE MEDIUM)

PARTICLES

Intermedia Relationships

Particulates are perhaps the most prevalent of the intermedia pollutants, transferring readily from one medium to another, often with little change in form or character. Many are quite capable of change either as a cause or result of the transfer process, and bring about quite different effects than caused by the mere presence of solid particles.

Metallic salts and oxides, which may be significant as particulates in the atmosphere, when collected and discharged to receiving waters can affect the pH. Organics, when removed from wastewaters and incinerated, can easily be transferred to the atmosphere as particulates. Other examples are so numerous that they are best defined by following their paths through the intermedia flow chart , Figure 10.

The transfer of particulates from the atmosphere to either land or water may take place in three separate ways: the particulates may merely settle out, they may be washed out by the impact of rain drops, or they may rain out. In the latter case the particle serves as a nucleus for the formation of the rain drop.

Environmental impact

The particulate intermedia pollution relationships are schematically shown in Figure 10 . Particulates may have a widely varied chemical composition and in the atmosphere may become aerosols. Because of the diversity of their chemical and physical properties, particulates as a group are potentially damaging to all aspects of life, property, and aesthetics. Some particulates may be directly toxic to man (asbestos, compounds of lead, fluorine, beryllium, and arsenic).[2] Also, some tars which may appear as hydrocarbon particulates are carcinogenic.[3] Relatively inert particulates can act as adsorbent surfaces for gaseous pollutants (such as SO_2), enabling the latter to penetrate deep into the lungs and cause disease. Deposits of fine particulates on lung tissue can produce mucous flow and further complications, such as penetration of the particles through the alveolar membranes and eventual extraction into the lymphatic system.[4] Deposition of particulates in the lungs also causes a reduction in the pulmonary oxygenation rate.

Particulates, even when not entrained as aerosols, may participate directly in the corrosion of metals, and cause general deterioration of materials through deposition.[5] Costs of particulate removal by laundering, sandblasting, etc. are a very large part of the economic impact of air pollution.[6]

Reduction of atmospheric visibility is an important influence of particulates as aerosols, the aerosol particles acting both to scatter and absorb light.[7] The smaller the particle size, the more important its effect on visibility reduction and human health. A great portion of the environmental impact which is attributable to aerosol particulates is

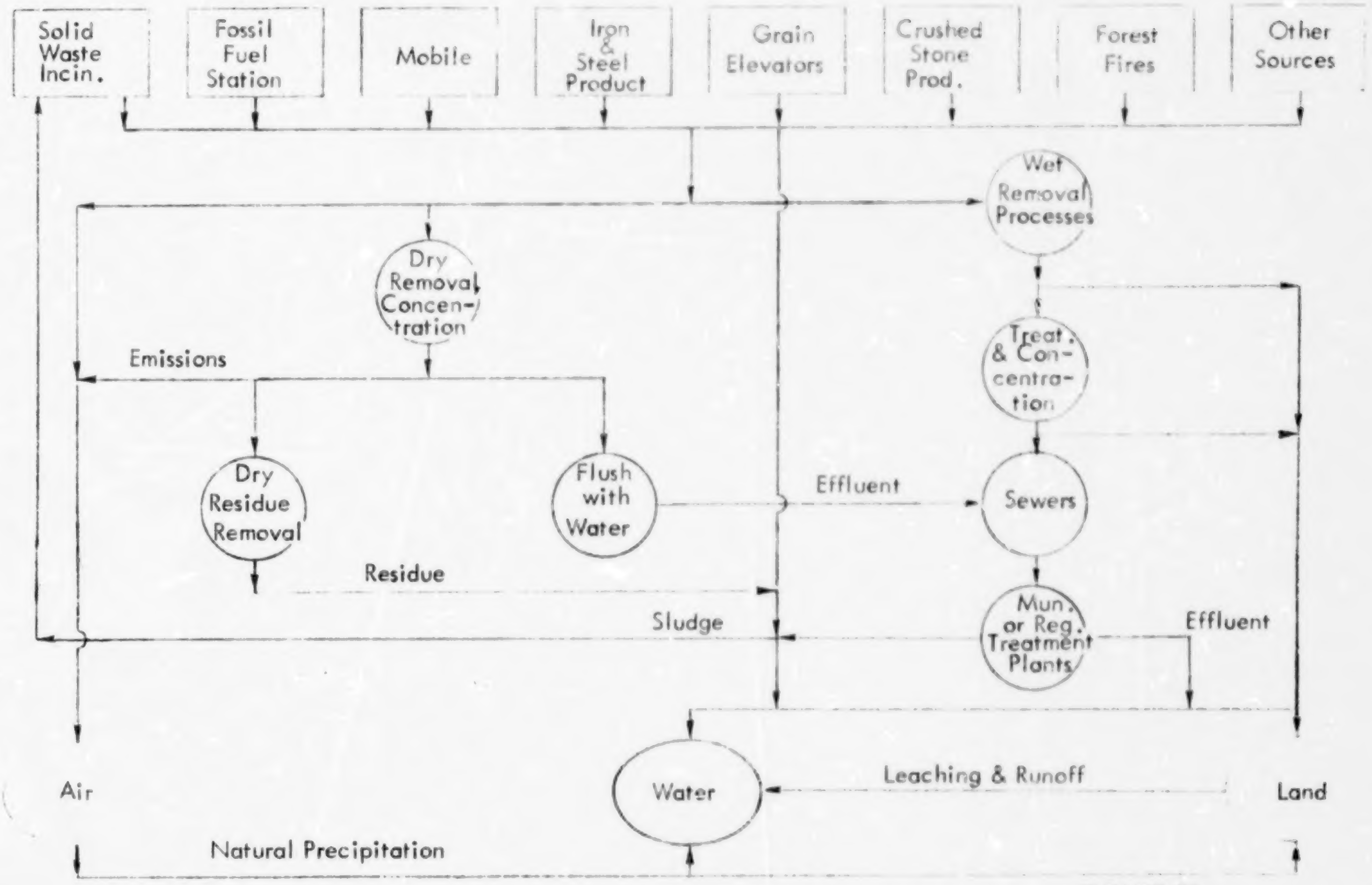

Solid Waste Incin.
Fossil Fuel Station
Mobile
Iron & Steel Product
Grain Elevators
Crushed Stone Prod.
Forest Fires
Other Sources
Wet Removal Processes
Dry Removal Concentration
Emissions
Treat. & Concentration
Dry Residue Removal
Flush with Water
Effluent
Sewers
Residue
Mun. or Reg. Treatment Plants
Sludge
Effluent
Air
Water
Leaching & Runoff
Land
Natural Precipitation

FIGURE 10
INTERMEDIA FLOW CHART
PARTICULATES

therefore, due to a relatively small percentage of the total pollutant mass. Additionally, the smallest aerosol particulates are the most difficult to remove by direct treatment.[8] The settlement of particulates in the environment is primarily a function of the size of the particulates. For example, particles of roughly spherical shape and less than one micron in diameter have atmospheric settling rates equal to or less than 0.01 ft/minute for a specific gravity of one, thus tending to remain suspended for long periods in the air. Data on the distribution of particulate sizes from many pollution sources is limited, although studies have been made on major sources.[10,11,12]

Figure 10 illustrates intermedia flows for particulate treatment decisions.

Main Sources

The primary particulate sources have been described by Vandegrift, Sallee, Gorman, and Parn.[13] A summary of the largest contributors appears in Table 9.

TABLE 9

PRIMARY PARTICULATE EMISSIONS[13]

Source	Emissions (tons/yr)
Fuel combustion - coal	5,704,000
Crushed stone	4,554,000
Grain elevators	1,700,000
Iron and steel production	1,421,000
Cement manufacturing	934,000
Forest products	666,000
Others	3,102,000
Total	18,081,000

Estimates by the national Environmental Protection Agency ascribe a significant contribution as well to solid waste incineration.[14]

Controls

Process Alternatives Where possible, wetting of work materials inhibits particulate emissions. In fuel combustion, particulate emissions may be reduced by substituting cleaner burning fuels (i.e. carbonaceous compounds with less unsaturation) or by promoting more complete combustion.

Treatment Alternatives Disposal of residues from particulate collection treatments can represent a major intermedia pollution problem[15] which may necessitate extensive wastewater treatment facilities. The latter treated residues should be ultimately disposed to land or landfill sites even though they may have received intermediate sludge or residue treatments.

Effective processing of collected particulates all rely upon the ultimate disposal of the collected residues to the land. Disposal to water bodies has caused pollution, and even land disposal leachate or drainage may cause some water pollution.

Treatment Methods

As previously described, particulates comprise a vast set of air pollutants, whose individual types may respond variously to treatment methods. Selection of treatment facilities must be decided with reference to intrinsic particle characteristics, primary production sources[3] and processes, device operation parameters including removal efficiencies, and residue-disposal considerations.[16] Particle characteristics to be considered are size distribution, shape, density, hygroscopicity, agglomerating tendency, corrosiveness, cohesiveness, adhesiveness, fluidity, electrical conductivity, flammability, and toxicity.[17] Among process factors to be considered are volumetric flow rate, variability of gas flow, particle concentration, allowable pressure drop, product quality requirements, and required removal efficiency. Availability of water and power, maintenance costs, needed floor space, vertical space, and construction material requirements (imposed by temperatures, pressures, etc.) must be considered as well. The residue-disposal factors to be considered are reusability within the plant, marketability, availability of suitable landfill area, water for piping, space for settling basins, access to municipal waste treatment systems, and general economic considerations.

Particulate extraction devices may be classified as gravity settling chambers, dry centrifugal collectors (cyclones), wet collectors and mist eliminators, electrostatic precipitators (low and high voltage), fabric filters, and afterburners. A summary of their advantages and disadvantages is presented in Table 10.

Indirect Gravity Settling Chambers A settling chamber is essentially a box in which emission velocity and turbulence is decreased by expansion of the gas to allow contained particles to settle out. Chambers of reasonable size produce through-chamber gas velocities of 1-10 fps.[16] Because capture is dependent upon the particle settling a required distance within the period of containment, the efficiency of such a treatment device is directly proportional to the length and width of the chamber, the settling velocity of the particles in the gas, and inversely proportional to the flow rate.[18] The settling velocity of the particles is dependent on particle size, shape, density, and on the viscosity of the medium.[16] Typical collection efficiencies are about 75 percent for particles larger than 45 microns while 30-40 percent removal of particles smaller than 45 microns is achievable.[19] Typical applications are as pre-cleaners for kiln and furnace exhausts,[20] and in handling of feeds and organic fibers.[21] For a high-efficiency type settling chamber such as the "Howard Separator" the approximate installed cost ranges from $500-$28,000 for 2000-100,000 cfm volumes, respectively. A typical annual maintenance cost is $0.015/cfm (range of $0.005-$0.025/cfm).[16] As with all particulate cleaners, residue disposal options are dependent upon the nature and quantities of the removed substance.

TABLE 10 ADVANTAGES AND DISADVANTAGES OF COLLECTION DEVICES[16]

Collector	Advantages	Disadvantages
Gravitational	Low pressure loss, simplicity of design and maintenance.	Much space required. Low collection efficiency.
Cyclone	Simplicity of design and maintenance. Little floor space required. Dry continuous disposal of collected dusts.	Much head room required. Low collection efficiency of small particles. Sensitive to variable dust loadings and flow rates.
	Low to moderate pressure loss. Handles large particles. Handles high dust loadings. Temperature independent.	
Wet collectors	Simultaneous gas absorption and particle removal.	Corrosion, erosion problems. Added cost of wastewater treatment and reclamation.
	Ability to cool and clean high-temperature, moisture-laden gases. Corrosive gases and mists can be recovered and neutralized. Reduced dust explosion risk.	Low efficiency on submicron particles. Contamination of effluent stream by liquid entrainment. Freezing problems in cold weather.
	Efficiency can be varied.	Reduction in buoyancy and plume rise. Water vapor contributes to visible plume under some atmospheric conditions.
Electrostatic precipitator	99+ percent efficiency obtainable.	Relatively high initial cost.
	Very small particles can be collected.	Precipitators are sensitive to variable dust loadings or flow rates.
	Particles may be collected wet or dry.	Resistivity causes some material to be economically uncollectable.
	Pressure drops and power requirements are small compared to other high-efficiency collectors. Maintenance is nominal unless corrosive or adhesive materials are handled.	Precautions are required to safeguard personnel from high voltage. Collection efficiencies can deteriorate gradually and imperceptibly.

TABLE 10 (cont.)[16]

Collector	Advantages	Disadvantages
	Few moving parts.	
	Can be operated at high temperatures (550° to 850°F.)	
Fabric filtration	Dry collection possible.	Sensitivity to filtering velocity.
	Decrease of performance is noticeable.	High-temperature gases must be cooled to 200° to 550°F.
	Collection of small particles possible.	Affected by relative humidity (condensation).
	High efficiencies possible	Susceptibility of fabric to chemical attack.
Afterburner, direct flame.	High removal efficiency of submicron odor-causing particulate matter.	High operational cost. Fire hazard.
	Simultaneous disposal of combustible gaseous and particulate matter.	Removes only combustibles.
	Direct disposal of non-toxic gases and wastes to the atmosphere after combustion.	
	Possible heat recovery.	
	Relatively small space requirement.	
	Simple construction.	
	Low maintenance.	
Afterburner, catalytic.	Same as direct flame afterburner.	High initial cost.
	Compared to direct flame: reduced fuel requirements, reduced temperature, insulation requirements, and fire hazard.	Catalysts subject to poisoning. Catalysts require reactivation.

Dry Centrifugal Collectors Dry centrifugal collectors remove particulate matter from exhausts through the centrifugal force produced by a spinning of the gas stream in the device. Particles discharged to the walls of the collector settle by gravity to a bottom outlet. Commonly called cyclones, these devices may create the spinning motion of the gas by vanes or tangential gas inlet. Energy may be added by fans to improve separation and there are a variety of flow configurations available.

In addition to the radial and gravitational forces, frictional drag of the particles is also a determinant of collector efficiency.[16] Cyclone efficiencies increase with particle size and density, inlet gas velocity, cyclone body length, the number of gas revolutions in the device, and smoothness of the cylone wall. Efficiencies decrease with increased gas velocity, cyclone diameter, size of gas outlet duct diameter and gas inlet area.[22] Average efficiencies are 50-80 percent for particles of 5-20 microns diameter, 80-95 percent for 15-50 microns, 95-99 percent for less than 40 microns. High efficiency cyclones may produce 99 percent removal efficiency for 50 microns particles and 95 percent for 20 microns.[23] Common applications of cyclones are in feed and grain mills, cotton gins, fertilizer plants, petroleum refineries, asphalt mixing plants, chemicals and metals manufacture, and metallurgical and wood fabrication operations.

For a medium efficiency cyclone installed costs may be $4,000, $23,000 and $80,000 for 10,000, 100,000 and 300,000 cfm flow rates. Annual maintenance costs are comparable to those for settling chambers, and annual operational costs are in the range of $500, $11,000 and $48,000 for the size installations noted above.[16]

Wet Collectors and Mist Eliminators Wet collectors, or scrubbers, are so varied in their design that only a general discussion will be presented here. In all such devices water is intermixed with the gas to be treated as an integral part of the collection mechanism. In so doing collection efficiencies are increased relative to dry mechanical collectors because of an effective size increase of the particles (conditioning), the applied energy of the water, minimizing of re-entrainment of collected particles by trapping in a water film and, in some applications, chemical reaction with the particles to be removed. Wet scrubbers may also be used for removal of some gaseous pollutants. Distinct types of wet-collection devices may be grouped as spray chambers, gravity spray towers, centrifugal spray scrubbers, impingement plate scrubbers, venturi scrubbers, packed bed scrubbers, self-induced spray scrubbers, mechanically induced spray scrubbers, disintegrator scrubbers, centrifugal fan wet scrubbers, inline wet scrubbers, irrigated wet filters, wet fiber mist eliminators, impingement baffle mist eliminators, vane-type mist eliminators, and packed-bed mist eliminators. Details of their design and operation may be found in reference 16. In all such devices efficiency and economy are dependent upon uniform and consistent distribution of the liquid, which is accomplished with various spray nozzles or spinning disk atomizers.[16]

Removal efficiencies vary with scrubber design type as well as particle and exhaust characteristics. Typically, a spray chamber can give 60-80 percent removal;[26] centrifugal spray scrubbers as high as 90 percent for 2-3 micron particles at a pressure drop of 1.3-2.3 in. water;[27] packed-bed scrubbers in excess of 90 percent for particles equal to or greater than 2 microns and high dust loadings (5 gr/scf)[28], and as high as 99 percent for some types equal to or greater than 2 micron particles;[29] disintegrator scrubbers at least 95 percent for 1 micron particles;[30] wet fiber mist eliminators in excess of 99 percent for particles less than 3 microns at 5-15 in. pressure drop; and impingement baffle mist eliminators 95 percent for 40 micron spray droplets of velocities up to 25 ft/sec.[16] Application of wet collectors is essentially as extensive as the range of industries. Typical applications are described in Table 11 (from reference 16).

For a medium-efficiency wet collector typical installed costs are $10,000, $55,000 and $150,000 for 10,000, 100,000 and 300,000 cfm flow rates. For very high efficiency devices these costs are typically increased to $20,000, $100,000 and $400,000, respectively. Annual operating costs on the same basis for medium-efficiency devices are $6,000, $45,000 and $130,000. Typical maintenance costs are $0.04/acfm ($0.02-$0.06).[15,16] Of necessity wet collectors require residue treatment considerations not inherently encountered with dry collectors. Settling tanks or lagoons may be utilized, where sufficient land area exists, in which particles of 1 micron or larger may be removed.[15,16] Where the solids have some recovery value, or are porous or incompressible, continuous filtrations may be employed.[31] Liquid cyclones and continuous centrifuges may be used, the former being inexpensive and the latter being efficient even with submicron slurries.[33] Chemical treatment is used extensively.[34,43] In addition, depending on its quality after treatment, the effluent water is either returned to the plant for reuse or discharged to a sewer or watercourse.

High-voltage Electrostatic Precipitators The high-voltage electrostatic precipitator removes particulate matter from gaseous exhausts by electrical charging of the suspended matter, followed by its collection on a grounded surface and subsequent mechanical removal to an external receptacle. Charging is accomplished by the passing of the particulates through a corona established between a charging electrode and a grounded electrode, and ultimate removal is effected by gravity and by mechanical devices or liquid flushing. Direct current voltages of 30-100KV are employed. Discharge and collection surfaces may be of several different shapes and sizes, and various cleaning methods may be used.

Typical efficiencies of electrostatic precipitators are very high, and may be expected to remain at peak levels for the life of the installation barring overloading, inadequate maintenance, or unfavorable process changes.[16] Significantly, use of low-sulfur coal to reduce SO_x emissions has a deleterious effect on precipitator efficiency.[44] Removal[45] efficiencies may otherwise be expected in the range of 75-85 percent, but can be as high as 99 or 99.9 percent.[5,16,19,46,47] High-voltage precipitators find application throughout industry, and especially for treatment of large emission volumes (50,000-2,000,000 cfm). Coal-fired power plants, steel making, cement manufacture, kraft pulp mills, and petroleum refineries are common users. Electrostatic precipitators may be operated at pressures from slightly below atmospheric to 150 pounds per square inch, and from ambient air temperature to 750°F.

TABLE 11[16]

TYPICAL INDUSTRIAL APPLICATION OF WET SCRUBBERS

Scrubber Type	Typical Application
Spray chambers	Dust cleaning, electroplating, phosphate fertilizer, kraft paper, smoke abatement
Spray tower	Precooler, blast furnace gas
Centrifugal	Spray dryers, calciners, crushers, classifiers, fluid bed processes, kraft paper , fly ash
Impingement plate	Cupolas, driers, kilns, fertilizer, flue gas
Venturi:	
Venturi throat Flooded disk Multiple jet	Pulverized coal, abrasives, rotary kilns, foundries, flue gas, cupola gas, fertilizers, lime kilns, roasting, titanium dioxide processing, odor control, oxygen steel making, coke oven gas, fly ash
Venturi jet	Fertilizer manufacture, odor control, smoke control
Vertical venturi	Pulverized coal, abrasive manufacture
Packed bed:	
Fixed	Fertilizer manufacturing, plating, acid pickling
Flooded	Acid vapors, aluminum inoculation, foundries, asphalt plants, atomic wastes, carbon black, ceramic frit, chlorine tail gas, pigment manufacture, cupola gas, driers, ferrite, fertilizer
Fluid (floating) ball	Kraft paper, basic oxygen steel, fertilizer, aluminum ore reduction, aluminum foundries, fly ash, asphalt manufacturing
Self-induced spray	Coal mining, ore mining, explosive dusts, air conditioning, incinerators
Mechanically-induced spray	Iron foundry, cupolas, smoke, chemical fume control, paint spray
Disintegrator	Blast furnace gas
Centrifugal inline fan	Metal mining, coal processing, foundry, food, pharmaceuticals
Wetted filters	Electroplating, acid pickling, air conditioning, light dust

TABLE 11 (cont.)

Scrubber type	Typical Application
Dust, mist eliminators:	
Fiber filters	Sulfuric, phosphoric, and nitric acid mists; moisture separators; household ventilation; radioactive and toxic dusts, oil mists
Wire mesh	Sulfuric, phosphoric, and nitric acid mists; distillation and absorption
Baffles	Coke quenching, kraft paper manufacture, plating
Packed beds	Sulfuric and phosphoric acid manufacture, electroplating spray towers

Typical installed costs of high-voltage precipitators are $120,000, $265,000 and $415,000 for 100,000, 300,000 and 500,000 cfm flow rates.[16] A high-efficiency unit at 500,000 cfm may cost in excess of $1,000,000 installed.[16,45] Maintenance costs may be expected to vary only slightly from $0.02/acfm annually, and annual operating costs for medium-efficiency units can be expected to be about $22,000, $60,000 and $85,000 for 100,000, 300,000 and 500,000 cfm flow rates respectively,[16] where cfm indicates actual cubic feet per minute.

Low-voltage Electrostatic Precipitators The low-voltage, two-stage, electrostatic precipitator was originally designed to purify air, and as an industrial particulate collector it is limited almost entirely to collection of fine-divided liquid particles. Typical efficiencies are 50-90 percent in the areas of application, which are essentially restricted to meat smokehouses, deep-fat cookers, high-speed grinding operations and asphalt saturators.[16] Because the sources controlled are relatively few and are minor polluters, this device will not be further considered here.

Fabric Filtration Fabric filtration is one of the oldest methods of particulate collection and one of the most efficient. The principle of operation is like that of a vacuum cleaner, in which the emissions to be cleaned are passed through bags of a woven or felted fabric. Envelope- and tube-shaped bags are generally used. Depending on the size, density, and electrical properties of the particles, entrapment is accomplished by direct interception (slipstream effects), inertial impaction[48] (direct collision), diffusion (for very small particles at slow flow rates),[49] electrostatic attraction,[50] and gravity settling.[51] Open spaces in the filter cloth are much greater than the size of particles to be collected, so simple fabric sieving is not the usual mode of entrapment.[16] The accumulated dust cake affords filtering characteristics in addition to the "clean cloth resistance;" thus both must be considered in the choice of a filtering unit.

Using fabrics of cotton, wool, dacron, nylon, orlon, nomex, polypropylene, teflon and fiberglass in various types of weaves or felted woolen fabric, a great range of efficiencies is possible. Efficiencies of 99+ percent with woven fabrics are common,[52,53,54] and efficiencies in excess of 99.7 percent are possible with felted fabrics.[55] Typical applications of fabric filters are as final cleaners for cement kilns, in foundries, for steel and nonferrous metal furnaces, and grain handling operations.[16] Of the 37 carbon black plants in the United States, 35 utilize fabric filters for final gas cleaning.[56]

In addition to the size of the baghouse and the characteristics of its operation (open pressure, closed pressure, closed suction) and the type of fabric used, the method of cleaning the filter bags is also a determinant of the cost of the unit. Capital and operating costs of baghouses are more varied than those of other particulate collectors, but for medium temperatures, synthetic fabric, and with continuous automatic cleaning, typical installed costs are $15,000, $100,000 and $400,000 for 10,000, 100,000 and 500,000 cfm flow rates. Costs of high temperature fabric installations are about twice as much in the same range. Annual operation costs for medium-temperature units are $3,500, $14,000 and $100,000 for 10,000, 100,000 and 500,000 cfm respectively. Annual maintenance costs are fairly high, at $0.05/cfm typically, ranging from $0.02-$0.08/cfm.[16]

Afterburners Afterburners do not collect particulate matter, but oxidize it to compounds which are expected to be less noxious, such as water and carbon dioxide. Direct-flame incineration or catalytic combustion may be employed. The use of afterburners is necessarily restricted to the control of combustible material, i.e. having a high hydrocarbon content, and to exhausts which are residue-free. Efficiencies are extremely high in areas of application, which generally involve odor control in very dilute gases.[16] Because afterburners are more widely applied for control of carbon monoxide and other gaseous pollutants than for particulates, they will not be further discussed here.

Residues from Control Devices

Residues created may be handled either dry or wet. Electrostatically precipitated fly ash from coal-fired power plants has found uses in building block construction and in sludge conditioning.[16]

MAJOR INTERMEDIA WATER POLLUTANTS (SINGLE MEDIUM)
ORGANICS

Organics in water most commonly are reported as measured biochemical oxygen demand. The latter is not a physical pollutant but an indicator. Other common measures of organics content are chemical oxygen demand, and total organic carbon. Five-day biochemical oxygen demand (BOD_5) indicates the amount of oxygen consumed in the decomposition of organic matter by bacteria in a given sample volume over a period of 5 days at 20°C.[107] Thus BOD is a measure of the oxygen-depleting effects of the contained organic matter. The oxygen consumed may ultimately be incorporated into water, carbon dioxide and compounds of nitrogen and sulfur,principally. Not all organic matter is rapidly bio-degradable since organic substances may have widely different carbon-hydrogen ratios and refractory characteristics.

Intermedia Relationships

There are three methods by which organics may be removed from their primary medium, water, and transfered to an alternate medium. One of these methods transfers the pollutant to air and the other two transfer it to the land. All three transfers result from residue disposal as shown in Figure 11.

The water to air transfer is achieved by incineration of the sludge produced by any of the treatments mentioned below. If this sludge is disposed to a landfill, the pollutant is transfered to the land. A more positive transfer of the pollutant to the land occurs if the treated or partially treated wastewater effluents and/or sludges are discharged on crop or forage lands. This transfer makes the nutrients available for plant growth and utilizes the solids for their nutrient and soil conditioning values. Biochemical oxygen demand is not then a significant consideration provided that runoff to adjacent watercourses is prevented or controlled.

Environmental Impact

When organic material is discharged into receiving waters, its biodegradation consumes the oxygen in the water. As the biochemical oxygen demand increases, the dissolved oxygen is rapidly depleted, depriving the fish and other aerobic organisms of their needed oxygen. When the dissolved oxygen drops to about 46 percent of saturation, fish will not enter the area.[108] At the same time, high organic concentration encourages eutrophication with the rapid growth of both algae and bacteria. This combined symbiotic activity and the resulting floatable by-products can produce undesirable scum, suspended solids,and bottom sludge deposits in the water body. Aside from the environmental and esthetic impacts, high social costs, economic costs of treatment and the costs of resource destruction are all related to the degradation of the receiving waters.[70]

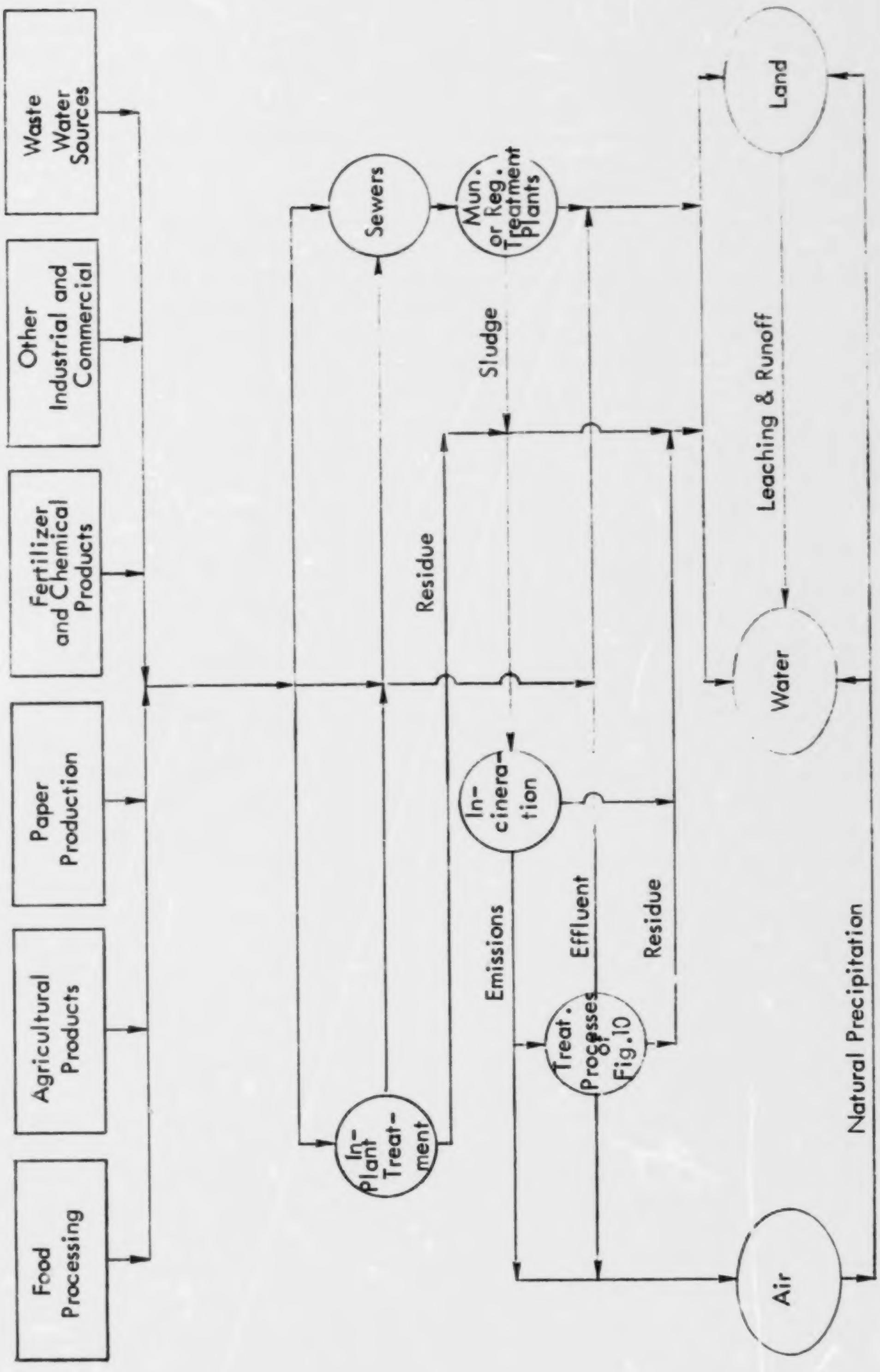

Food Processing
Agricultural Products
Paper Production
Fertilizer and Chemical Products
Other Industrial and Commercial
Waste Water Sources
In-Plant Treat-ment
Sewers
Residue
Sludge
Mun. or Reg. Treatment Plants
In-cinera-tion
Emissions
Effluent
Residue
Treat. Processes of Fig. 10
Air
Water
Land
Leaching & Runoff
Natural Precipitation

FIGURE 11
INTERMEDIA FLOW CHART
ORGANICS AND SUSPENDED SOLIDS IN WATER

Main Sources

Table 12 shows the reported quantities of industrial wastewaters discharged in 1963 and Federal Water Pollution Control Agency (FWPCA) estimates of the quantities of organics measured as BOD_5 and the settleable and suspended solids contained in these waters. These data agree fairly well with the independent but more limited data of this study. Wasteload estimates indicate that industries included in the categories of chemicals (SIC 28), paper (SIC 26) and food and kindred products (SIC 20) generated about 90 percent of all BOD_5 in industrial wastewater before treatment.[109]

Controls

A typical process change to reduce the discharge of organic wastes would be the substitution of dry processes for treating and cleaning in industries. Recirculation and reuse of process waters and the treatment of waste waters for product recovery are other changes that may be used. Better housekeeping to reduce discharge of wastes to the sewers and better utilization of materials will also help.

Treatments

A number of treatment processes have been proven effective in the stabilization of organics; many are in common use today. The processes range in efficiency from about 40 percent to more than 98 percent removal of BOD_5. Table 13 shows relative efficiencies of various treatment processes. These methods include: fine-screening (5-10 percent),settling and flotation (5-40 percent),chemical precipitation (78 percent);[84] activated sludge (85-95 percent);[110,111] trickling filter (80-95 percent);[112] stabilization ponds (70 percent);[113] and carbon adsorption (85-98 percent).[114,115,116] All of these methods generate gaseous and solid residues which present the ultimate disposal requirement with intermedial effects mentioned above. The available treatment cost information is presented in Section VI.

TABLE 12

SELECTED ESTIMATED VOLUME OF INDUSTRIAL WASTES BEFORE TREATMENT, 1963[109, a]

PPB[b] Code	SIC[c] Code	Industry Group(s)	Total[d] Wastewater, (Billion Gallons)	Process Water Intake, (Billion Gallons)	Standard Biochem. Oxygen Demand[l] (Million Pounds)	Settleable and Suspended Solids (Million Pounds)
1201	33,34	Metal & Metal Products	> 4,300	1,000	> 480	> 4,700
1202	28	Chemical & Allied Products	3,700	560	9,700	1,900
1203	--	Power Production	NA[e, f]	N.A.[f]	N.A.[f]	N.A.[f]
1204	26	Paper & Allied Products	1,900	1,300	5,900	3,000
1205	29	Petroleum & Coal	1,300	88	500	460
1206	20	Food & Kindred Products	690	260	4,300	6,600
1207	35,36, 37	Machinery & Transportation Equipment	> 481	109	> 250	> 70
1208	32	Stone, Clay, and Glass Products	218[e]	88	N.A.	N.A.
1209	22	Textile Mill Products	140	110	890	N.A.
1210	24,25	Lumber & Wood Products	126[e]	57	N.A.	N.A.
1211	30	Rubber & Plastics	160	19	40	50
1212	12,19, 21,27, 31,38, 39,72	Miscellaneous Industrial Sources	450	190	> 390	> 930
1200		All Manufacturing	≥ 13,100	≥ 3,700	≥ 22,000	≥ 18,000
		For Comparison: Sewered Population of U.S.	5,300[g]	N.A.	7,300[h]	8,800[k]

(a) Ref: Volume II - The Cost of Clean Waters. 1968.(b) Program Planning & Budget.(c) Standard Industrial Classification. (d) Includes Cooling Water & Steam Production Waters.(e) Included in Total for all Mfg.(f) Not Available or Not Applicable. (g) 120,000,000 persons x 120 gallons x 365 days.(h) 120,000,000 persons x 1/6 pounds x 365 days.(k) 120,000,000 persons x 0.2 pounds x 365 days. (l) BOD_5 20°C

TABLE 13

RELATIVE EFFICIENCIES OF SEWAGE-TREATMENT PROCESSES

PERCENTAGE REMOVAL

	Treatment Process	Biochemical Oxygen Demand[a]
1.	Fine screening	5 to 10
2.	Chlorination of raw or settled sewage	15 to 30
3.	Plain sedimentation	25 to 40
4.	Chemical precipitation	50 to 85
5.	Rapid filtration preceded by plain sedimentation	35 to 65
6.	Rapid filtration preceded by chemical precipitation	50 to 90
7.	Trickling filtration preceded and followed by plain sedimentation	80 to 95
8.	Activated-sludge treatment preceded and followed by plain sedimentation	85 to 95
9.	Intermittent sand filtration	90 to 95
10.	Chlorination of biologically treated sewage	. . . .[b]

---

[a] 5-day, 20°C.

[b] not applicable to BOD.

SUSPENDED SOLIDS

As with particulates in the atmosphere, suspended solids (SS) in the liquid medium are made up of many different types of materials. The majority of suspended solids are organic in nature and therefore exert a biochemical oxygen demand on the receiving waters. Suspended solids are determined as the residue that can be removed by filtration, as opposed to dissolved solids, which are determined by evaporation.[117]

Intermedia Relationships

Because of the ease with which solids can be transferred between media, suspended solids are included in the flow chart for particulates (Figure 9). The major difference between particulates in the air and suspended solids in the water is the amount of natural transfer which takes place between media. In the section on particulates, natural transfer was shown to be fairly extensive. Figure 9 shows that transfer out of the water medium by natural processes is far less so. Some man-controlled processes such as residue disposal from treatment processes do effect intermedia transfers. This may be through incineration or land disposal.

Environmental Impact

In addition to the oxygen demand problem caused by the organic fraction of suspended solids, other problems also result. Among these are aesthetic degradation and interference with the growth, survival, and propagation of algae, plants, fish and shellfish. Aside from any toxicity which may exist, suspended solids may kill fish, shellfish, and other aquatic life through abrasive injuries, by clogging gills and respiratory passages, by smothering eggs, young, food chain organisms, and by destroying spawning beds.[118] In concentrations over 750 mg/l, the development of eggs and larvae of the venus clam is decreased.[119] In a river containing 6,000 mg/l of suspended solids, trout population was one-seventh and that of invertebrates one-nineteenth the comparable densities in a control river source.[120]

Controls

Controls for the limitation of suspended solids are essentially the same as for organics. Waste water treatment processes have efficiencies of suspended solids removal ranging from 50 to more than 98 percent. These processes, even when not intended primarily for suspended solids removal, have the following approximate efficiencies: screening, 0 -80 percent; flotation, 70-95 percent;[121] chemical precipitation, 70-90 percent; primary sedimentation, 50-90 percent;[122] activated sludge, 85-95 percent;[123] trickling filter, 70-92 percent;[112] carbon adsorption, 90 percent;[122] sand filtration 70-90 percent and coagulation, sedimentation, sand filtration 90-99+ percent. The available treatment cost information is presented in Section VII.

ACIDITY AND ALKALINITY

Metallic salts and oxides in water hydrolyze to form acids and alkalies which in turn affect the pH of the water. When wastes containing metallic salts and oxides are discharged in sufficient quantities into natural water bodies, the pH of the latter may also be changed. Like biochemical oxygen demand, pH is not a pollutant, but only an indicator of pollution.

Intermedia Relationships

Even when volatile acids and bases are dissolved in water at reasonable concentrations, they are not easily transferable to air. On the other hand, water scrubbing of gases containing SO_x and NO_x provides an air-to-water intermedia transfer route. Figure 12 shows the intermedia flow for acidity and alkalinity.

Environmental Impact

A slight change in pH can produce an alteration in the carbonate buffer system on which living organisms rely.[210] Another primary danger which may accompany a change in pH is the synergistic effect of acidity and waterborne substances producing toxicity. For example, a reduction in pH of about 1.5 units can cause a thousandfold increase in the acute toxicity of cyanometallic complex.[210]

Not all plant and animal life have the same tolerance to pH changes. Most fish can withstand a variation in pH between 5.0 and 9.0.[66] Beyond this range, replacement communities take over.[211] A high or low pH in livestock watering supplies can be detrimental to the animals.

Other Effects

Industries which either use waters polluted with metallic salts and oxides or have these pollutants in their wastewater, may have serious problems because of the hardness of the water. Industries which use these hard waters generally soften them to prevent the waters leaving a scale deposit on the inside of process tanks, pipes, and boilers. These deposits can decrease the efficiency of the system, shorten its useful life, or even damage it. Industries which discharge these latter pollutants usually have them in large quantities. The metallic salts cause corrosion of pipes, pumps, and other structures made of metal or concrete.[66] Some salts of non-toxic metals (iron and aluminum, for example) react with the natural alkalinity in the water to form stable hydroxides. Some of these are colored and form unsightly deposits in the receiving waters.[66] It is believed that the latter deposits reduce light penetration of the river and interfere with normal, existing ecological systems.[212]

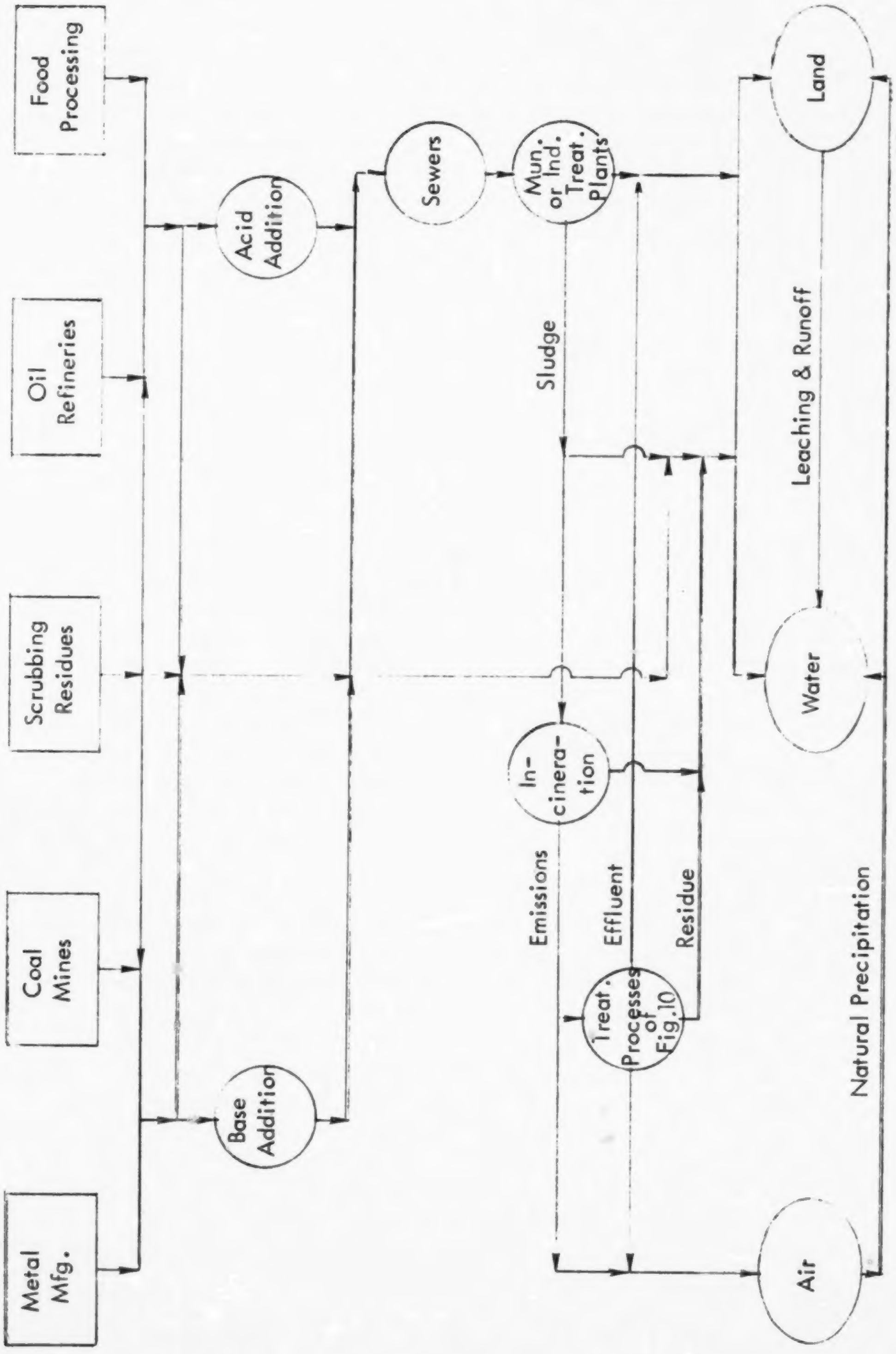

Metal Mfg.
Coal Mines
Scrubbing Residues
Oil Refineries
Food Processing
Base Addition
Acid Addition
Sewers
Mun. or Ind. Treat. Plants
Sludge
Treat. Processes of Fig. 10
Emissions
Effluent
Residue
In-cinera-tion
Air
Water
Land
Leaching & Runoff
Natural Precipitation

FIGURE 12
INTERMEDIA FLOW CHART
ACIDITY - ALKALINITY

Main Sources

The metallic salts and oxides are likely to be formed by any waste generator which employs metal in its process or piping. This is true of the transportation equipment,[57] mining,[45] primary metals industries[213,214] and fabricated metals products .[87,90] The largest U.S. source is acid drainage from coal mines, the pollutant being sulfuric acid produced by air oxidation of pyrites. These waters may have a pH as low as 2.9.[218] Acid pickling of steel is another source of acidity in waste effluents.[219] At the other end of the pH scale, refinery wastes[220] and food processing wastes are highly alkaline, in part.[221]

Controls

The most common treatment for acid or alkali waste water is to neutralize it by adding the appropriate basic or acidic solution. The most common alkalies used to neutralize acids are limestone, lime, and soda ash. Sulfuric acid is most commonly used to neutralize basic solutions. Carbonic or nitric acids are also used to a lesser degree. The available treatment cost information is presented in Section VI.

PHOSPHORUS COMPOUNDS

Intermedial Relationships

Figure 13 illustrates the intermedial relationships for phosphorus compounds. The main sources are agricultural runoff, urban drainage, food processing, chemicals and allied industries, and waste water from other sources. Agricultural runoff and urban drainage may flow directly to receiving waters, although urban drainage may be directed through combined sewers to treatment plants where it may or may not be bypassed.

The wastes from the food processing industry and chemicals and allied products industry may or may not receive in-plant treatment, either partial or complete. The effluent from in-plant treatment may either be discharged to sewer systems or directly to the water or land. The residues from treatments may be incinerated, discharged to receiving waters or deposited in landfills. The incineration process creates emissions which may or may not be treated. These possible treatments were discussed under "Particulates" and are shown in Figure 9 . The residues from these treatments may be disposed to either the land or water. Figure 13 also illustrates the natural intermedia flows. Phosphorus compounds may leach from landfills or run off from the land to receiving waters, where they provide nutrients to plant growth. They may also precipitate from the air to water and land.

It should be mentioned here that incineration does not transfer a large amount of gaseous phosphorus compounds (such as phosphine) to the air. This intermedia route, then, is less significant for phosphorus than it is for sulfur compounds.

Environmental Impact

The major impact of phosphorus in water is similar to that of nitrogen. As a nutrient, phosphorus promotes algal growth in the same manner and with the same consequences and can be removed for approximately the same cost.[70] Phosphine (PH_3), the final compound in the biological breakdown of phosphates, is toxic to certain fish,[69] and has been detected in some polluted waters in concentrations exceeding 3.6 mg/l. [124, 125, 126]

Main Sources

Phosphorus has received much recent attention because of its use in detergents and the resulting increase in the phosphate content of sewage.[79] Other sources of phosphorus in wastewater are agricultural production,[79, 127, 128] food and kindred products,[78] chemicals and allied products,[64, 65] and urban drainage.

Controls

Controls on the discharge of phosphorus compounds to receiving waters are limited primarily to use of substitute materials and interception of surface drainage. No-phosphate detergents are an example of the former, while use of drainage ditches, impoundment and spreading are frequently employed for the latter.

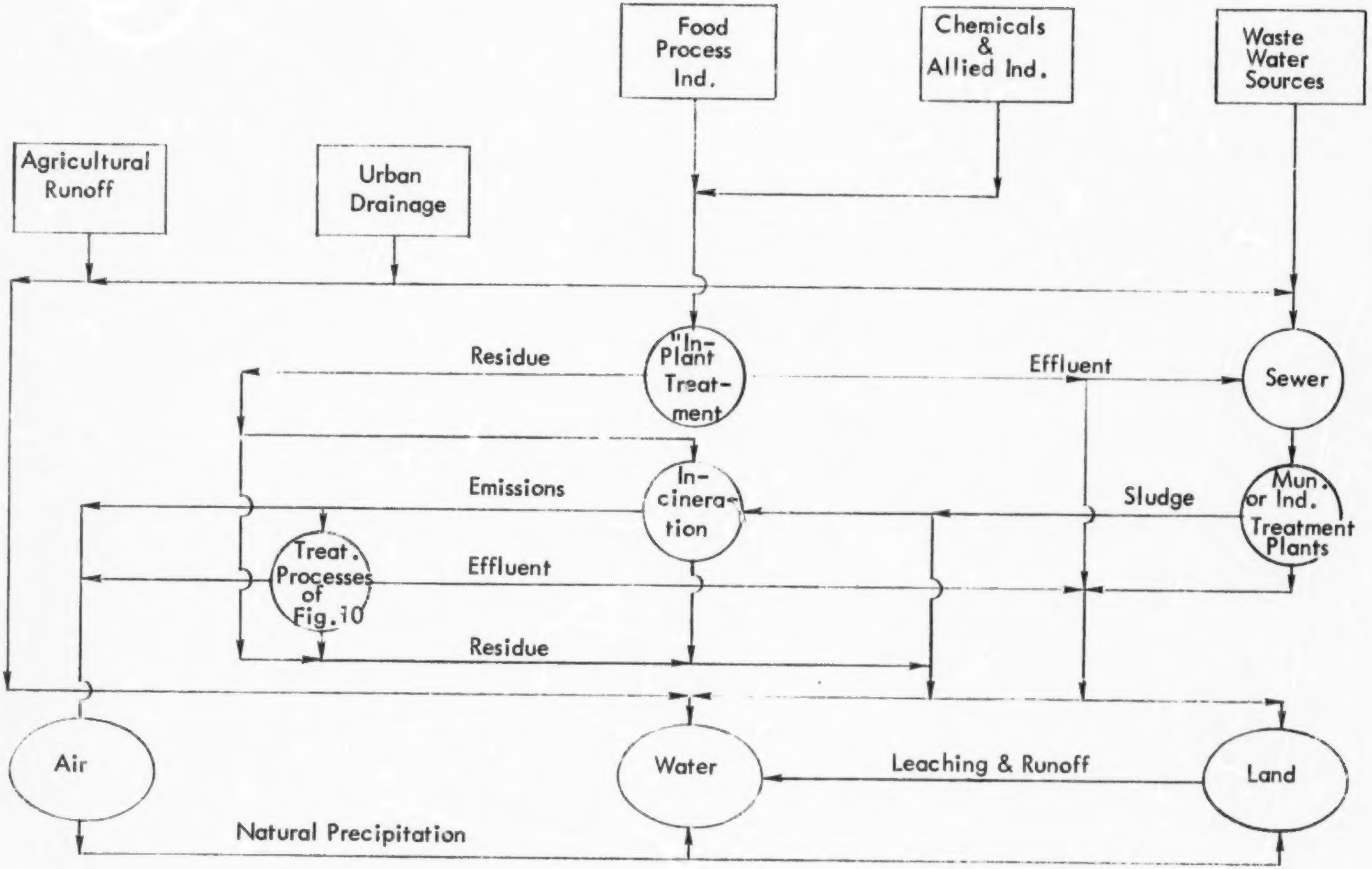

Food Process Ind.
Chemicals & Allied Ind.
Waste Water Sources
Agricultural Runoff
Urban Drainage
"In-Plant Treatment
Residue
Effluent
Sewer
In-cineration
Emissions
Sludge
Mun. or Ind. Treatment Plants
Treat. Processes of Fig. 10
Effluent
Residue
Air
Water
Leaching & Runoff
Land
Natural Precipitation

FIGURE 13
INTERMEDIA FLOW CHART
PHOSPHORUS COMPOUNDS

Treatments

There are a number of treatment processes which will remove phosphorus and its compounds from wastewater, through either the formation and precipitation of insoluble phosphorus compounds, phosphorus uptake, or capture and removal with the sludges. Some of these methods and their efficiencies are chemical precipitation, 88-95 percent by itself, 95-98 percent if followed by filtration; carbon adsorption, 32 percent; electrodialysis, 10-40 percent; and ion exchange, 86-98 percent. Biochemical processes which are capable of phosphorus removal are activated sludge and algal harvesting. The available treatment cost information is presented in Section VI.

LESSER OR INTRAMEDIAL AIR POLLUTANTS (SINGLE MEDIUM)

With the exceptions of carbon monoxide and hydrocarbons, which are major intramedia air pollutants, the pollutants in this section are lesser pollutants which are not of national concern. Information relating to fluorides, hydrogen chloride, arsenic, hydrogen cyanide, ammonia and ethylene is very limited and it is not possible to develop accurate national emission data for these pollutants. Therefore, the discussions of these pollutants will include a brief paragraph about the intermedia relationships and one concerning the environmental impact of the pollutant. No flow charts have been developed except for carbon monoxide and hydrocarbons. The discussions will briefly give the reasons for classifying these pollutants as of lesser importance in accord with the criteria presented in "Major vs. Lesser Pollutants," Section III.

CARBON MONOXIDE

Intermedia Relationships

Because of its low water solubility and low hygroscopicity carbon monoxide is not easily transferred to water or land by physical means (rainwash). Unless oxidized to CO_2, it remains essentially a serious air pollution problem. In spite of the great quantities of man-made CO emitted, if it were all oxidized to CO_2 the result would be only about one percent of all man-made CO_2 emissions.[63] This oxidation pathway is, therefore, insignificant for CO in terms of the intermedia implications of CO_2.

Furthermore, the nature of treatment methods for carbon monoxide is such that intermedia transfer from air to water is essentially precluded (Figure 14). As CO from man-related sources results solely from incomplete combustion, which is inherently an air-polluting process, there is very little water pollution by CO. Carbonates discharged to water are reducible to carbon monoxide only with extreme difficulty. The important features of CO pollution and its fate in the environment are discussed below.

Environmental Impacts

At concentrations of about 1000 ppm, carbon monoxide is quickly lethal to humans. It kills by oxygen starvation[3] since CO is preferentially chelated by hemoglobin as compared to oxygen. At 100 ppm carbon monoxide induces lassitude, headache and dizziness in humans.[59] The highest concentration of CO recorded at a fixed site in Los Angeles, California was 72 ppm,[96] although instances of concentrations higher than 100 ppm have been found in Los Angeles traffic[87] and in heavy traffic areas of Detroit, Michigan.[88] There is some concern that CO_3 may be a chronic poison,[89] but this position has few adherents in the United States.[3]

There is no evidence for chronic carbon monoxide damage to vegetation, materials, animals, or aesthetics at normal pollution levels.[90]

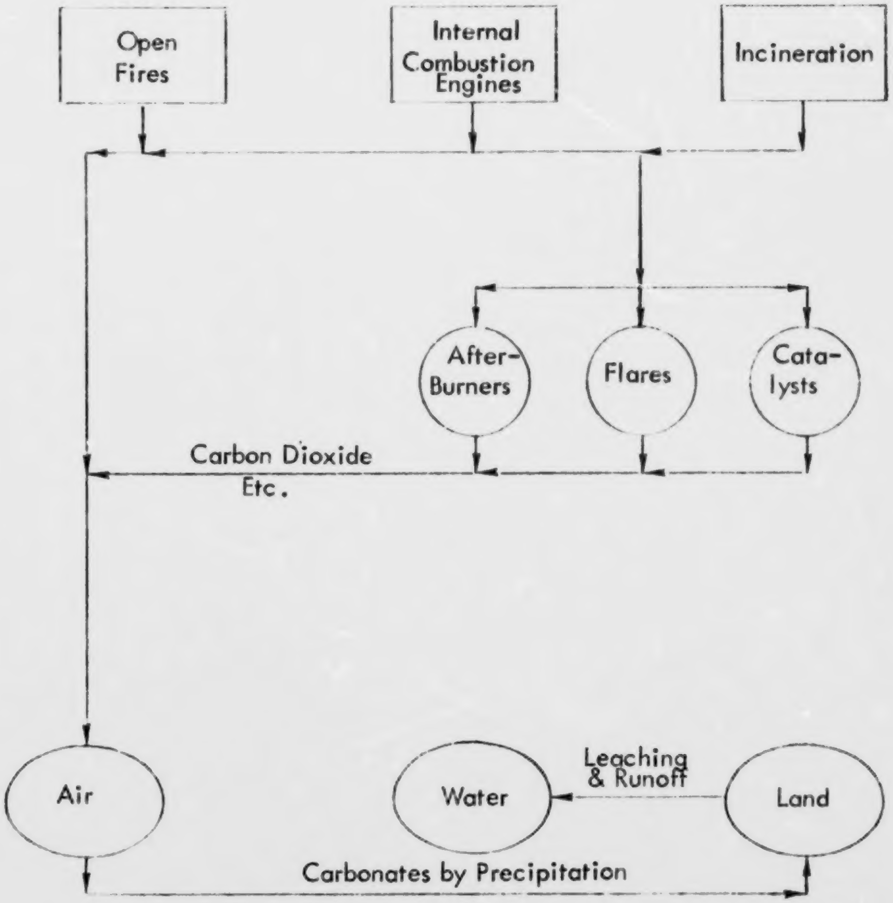

Open Fires
Internal Combustion Engines
Incineration
After-Burners
Flares
Cata-lysts
Carbon Dioxide Etc.
Air
Water
Leaching & Runoff
Land
Carbonates by Precipitation

FIGURE 14
INTERMEDIA FLOW CHART
CARBON MONOXIDE

At high concentrations carbon monoxide is known to participate in synergistic toxic reactions with several other gaseous pollutants.[3] However, at CO concentrations generally encountered in the atmosphere,no such synergisms have been established.[5]

Main Sources

In terms of gross amounts, carbon monoxide is the most significant man-made pollutant, with an estimated 147.2 million tons emitted in 1970. Transportation sources account for about 75 percent of this total, or 111.0 million tons in 1970. Forest fires and other open burning are the second largest contributor, with about 17 million tons, followed by industrial processes and solid waste disposal.[14] In all such calculated estimates of nationwide pollutant emissions the method of calculation is highly important. A different method for calculating CO from automotive exhausts showed an "increase" from "63.8" to "111.5" million tons from 1968 to 1969.[90, 91] One further complicated estimate claims that 90 percent of all CO emissions to the global atmosphere, or about "3.5 billion tons per year," are the result of natural processes.[92] Waterways have been cited as CO emitters.[5] Carbon monoxide has been considered a uniquely man-related pollutant,[5] or at least its production from natural sources has been considered relatively unimportant or negligible.[63]

Treatments

The available treatment cost information is presented in Section VI. The controls, such as afterburners, are intramedial.

HYDROCARBONS

Intermedia Relationships

Examination of Figure 15 reveals transfer modes between the fluid media for hydrocarbon pollutants discharged originally to the air. However, it should be emphasized that the physical possibility of transferring hydrocarbon emissions from air to water is very slight, due to their water-insolubility and the efficiency of normal intramedial hydrocarbon treatment methods. Volatile hydrocarbons spilled or wasted to waterways will evaporate to air, and incineration of oily spills and sludges may transfer a small amount of unburned fuel. Some hydrocarbons are in particulate form, and may thus be treated by particulate control techniques. Figure 9 illustrates intermedia relationships for particulates.

Environmental Impact

Except for fused-ring aromatics, which may be carcinogenic, hydrocarbons are not generally harmful to human or animal life in relatively dilute atmosphere concentrations. In large concentrations they are asphyxiants because of oxyten exclusion.[93] Low-molecular weight hydrocarbons comprise nearly all the gross emissions and are either gases or liquids and are generally colorless at ambient temperatures. They do not generally form aerosols, hence they do not contribute directly to visibility reduction in the atmosphere.

A major impact of hydrocarbon pollutants involves their photochemical reaction with nitrogen oxides to form smog. Olefinic unsaturates are the most reactive, and parafinic hydrocarbons, the least.[5] The effects of these secondary pollutants were described previously in the Section on Nitrogen Oxides and Compounds.

Except for the high molecular weight hydrocarbons, which are settleable, hydrocarbon emissions tend to remain airborne. They are water insoluble and do not enter water resources except that the medium molecular weight compounds may enter as flotables. Because hydrocarbons are not easily transferred from the air, they pose a continual hazard as reactants to form such photochemical products as PAN.

Main Sources

Total hydrocarbon emissions to the atmosphere in the United States have been estimated at 34.7 million tons in 1970. Estimates have remained essentially constant at that value for the previous few years. Nearly 20 million tons are attributable to vehicular and other transportation sources, with miscellaneous sources contributing 7.1 million tons and industrial processes 5.5 million tons.[14] However, there is some controversy over the relative importance of man-related hydrocarbon emissions. It has been reported that natural sources such as vegetation and bacteria are responsible for 85 percent of the global hydrocarbon emissions[2] and 50 percent of all United States emissions.[98,99] However, natural sources are generally well removed from population centers, which may limit their importance as direct impactors on man's environment or reactants with

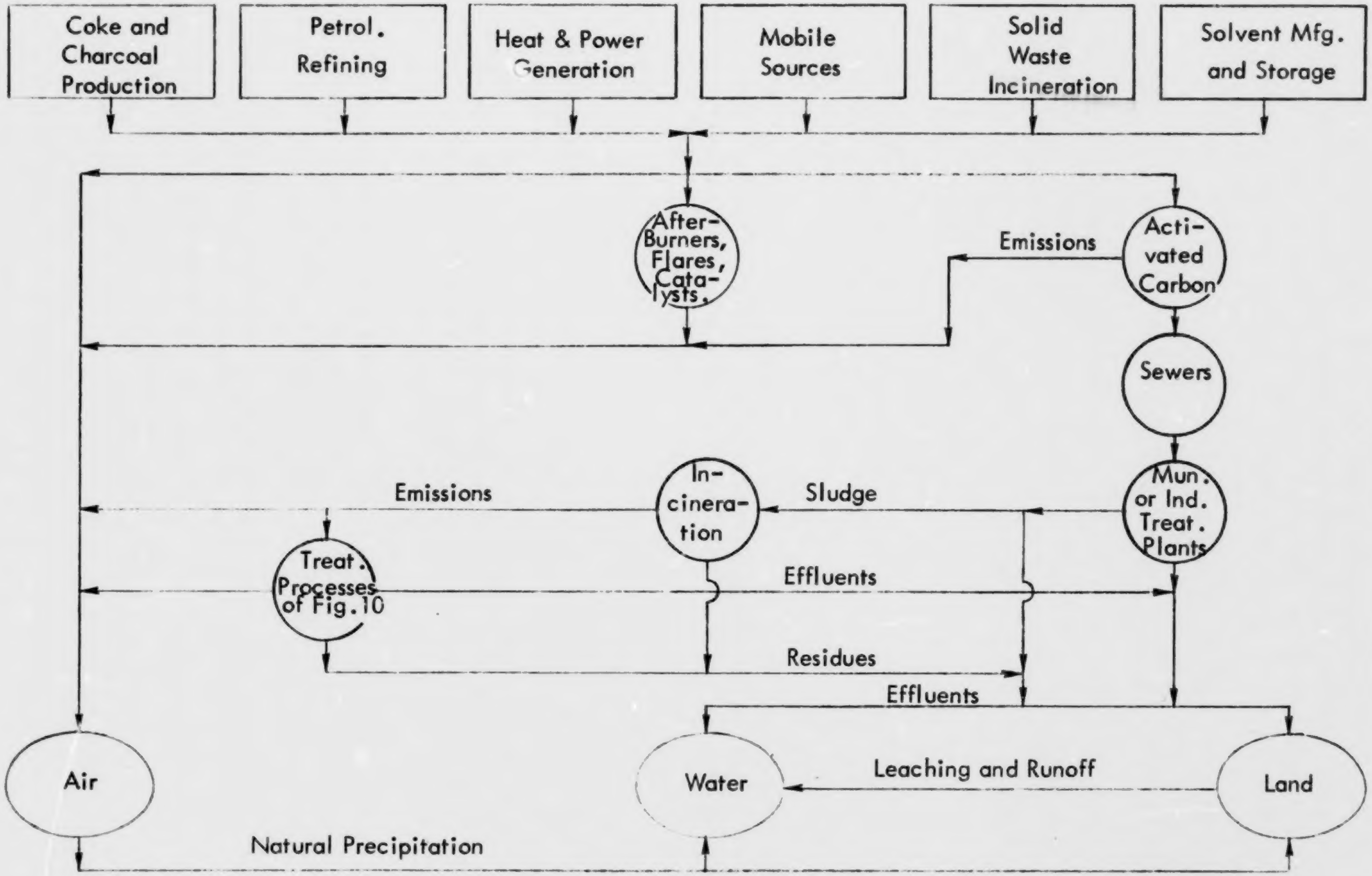

Coke and Charcoal Production
Petrol. Refining
Heat & Power Generation
Mobile Sources
Solid Waste Incineration
Solvent Mfg. and Storage
After-Burners, Flares, Cata-lysts.
Emissions
Acti-vated Carbon
Sewers
Emissions
In-cinera-tion
Sludge
Mun. or Ind. Treat. Plants
Treat. Processes of Fig. 10
Effluents
Residues
Effluents
Air
Water
Leaching and Runoff
Land
Natural Precipitation

FIGURE 15
INTERMEDIA FLOW CHART
GASEOUS HYDROCARBONS

man-made pollutants to form more damaging substances. Methane from swamps and terpenes from evergreen forests are examples of two predominant natural sources,[93,99] while gasoline constituents such as branched pentanes and benzene derivatives are the predominant hydrocarbons from man-related sources.[93] Although very low in atmospheric concentrations and total emissions, some high molecular weight fused-ring aromatic hydrocarbons like the benzopyrenes are known carcinogens.[100] They are produced by high-temperature combustion of organic substances as in coal and oil burning, incineration, backyard barbequeing, and cigarette smoking.

Sanitary landfills may also be a source of hydrocarbon emissions. Anaerobically decomposing organic wastes produce methane. The potential gross pollution by methane from such point source disposal methods may be far greater than the hydrocarbon emissions during solid waste incineration.

Controls

Means of reducing hydrocarbon emissions in the California South Coast Air Basin as planned by the Environmental Protection Agency, and as reported in the Los Angeles Times,[101] includes propane powered vehicles, improved service station design to lessen evaporation, reduction of hydrocarbon compounds used by industry, minimum reactive hydrocarbons used in degreasing, and lesser use of hydrocarbons in dry cleaning establishments. Hydroelectric and nuclear power plants are presently limited alternatives to fossil-fuel units for abatement of hydrocarbon emissions from power generation.

Treatments

Some hydrocarbons are in particulate form and may be controlled by standard particulate treatment procedures (see Particulates).[102] Afterburners and flares which are the most efficient treatments for hydrocarbons are not intermedia alternatives. Catalytic afterburners for automobiles may be poisoned by lead and other gasoline impurities. However, the reduction of hydrocarbon emissions in the past few years[14,90,91] may be attributed to the partial effectiveness of vehicular "smog-control" devices.

Evaporation and emissions from stationary point sources may be treated by adsorption on activated carbon,[103] by combustion in direct-fired afterburners for higher concentrations[104] or by catalytic afterburners for low concentrations.[103,56]

Hydrocarbons may be efficiently removed from stationary exhausts by activated carbon, which is steam-reactivated and provides recovery of the hydrocarbons. If the condensed steam were discharged into a watercourse it could carry with it the removed hydrocarbons as a surface film. However, adsorption and regeneration of activated carbon is an expensive process[106] and normally is utilized only when the recovered hydrocarbon may be isolated and reused or marketed. Adsorption on activated carbon is not normally a process for intermedia transfer of hydrocarbons. Hydrocarbons are not considered as one of the prime factors in intermedia pollution as all mobile controls and most stationary controls, except for activated carbon, are intramedial. Of course particulate hydrocarbons can follow particulate intermedia flows and are potentially most damaging to human health. The available control information is presented in Section VI.

FLUORIDES

Intermedia Relationships

Intermedia treatments do exist for some fluorides. Hydrogen fluoride, a common form, can be readily removed by scrubbing processes, thus creating a potential transfer to water.

Environmental Impacts

Fluorine is a cumulative poison and the degree of its toxicity is a function of both ingestion level and length of exposure. Fluoride ingestion causes a disturbed calcification of growing teeth. Fluorides are also a protoplasmic poison, a fact which finds its explanation in the blocking of certain enzyme systems.[18] Although there is no evidence to indicate widespread damage at the national level from fluorides, local problem areas do exist. Measurable amounts of fluoride may be found in the atmosphere of any coal burning city in the winter. Agricultural sprays and dusts containing fluorides have caused significant damage in rural areas.

HYDROGEN CHLORIDE

Intermedia Relationships

Hydrogen chloride can be controlled with methods similar to those for sulfur oxides. Some potential controls convert the compound to hydrochloric acid, as a water pollutant, but most control methods recover the gas so that intermedia transfer of hydrogen chloride is not widespread.

Environmental Impacts

Hydrogen chloride and other chloride compounds can cause widespread damage to vegetation and property. However, the modern alkali industry, a main source of this pollutant, is based upon the electrolysis of common salt and by-products are usually carefully controlled. Chlorine concentrations for U. S. cities are well below commonly-accepted danger levels.[18] Some local problems in rural areas can exist if precautions are not taken in the use of hydrogen chloride as a fumigant. Since this pollutant creates no major problem nationally nor is likely to become a major problem, no further analysis will be presented here.

ARSENIC

Intermedia Relationships

Arsenic is a heavy metal and can be controlled by the same techniques shown in Figure 8 and the accompanying treatment discussion of heavy metals. Arsenic is, therefore, an intermedia pollutant, though not a major one.

Environmental Impacts

The high level of toxicity of arsenic is widely known. Humans and animals suffer severe salivation, thirst, vomiting, great uneasiness, feeble and irregular pulse, and respitation. Death may come in a few hours or days.

The more common cases involve economic damage from animal deaths. The animal begins to stamp, alternately lies down and gets up; breath and feces may have a garlic odor and the feces may be bloody.[18]

Arsenic occurs as an impurity in ores and in coal, and has been reported to cause poisoning of livestock near various industrial processes and smelters. It is used in some insecticides in the form of arsenic trioxide and lead arsenate. This pollutant is considered a lesser intramedia pollutant.

HYDROGEN CYANIDE

Intermedia Relationships

Control methods for this pollutant consist mainly of safe handling, and thus hydrogen cyanide is classified as an intramedia pollutant.

Environmental Impacts

Hydrogen cyanide, while extremely lethal, is not a major air pollutant nationally. It can be fatal to animals and humans, and can also injure vegetation, causing surface irritation and root damage. It can cause root injury when leaked into greenhouses from underground gas lines,[18] since it has been found in artificial gas to the extent of 200 to 300 ppm. Hydrogen cyanide is used as a fumigant, and careless handling can cause the damage described.

AMMONIA

Intermedia Relationships

Where an industrial process emits high concentrations of ammonia, as mentioned above for fertilizer, organic chemicals and nitric acid, its value stimulates recovery for use rather than disposal of the residue, so no intermedia transfer takes place. In the case of agricultural problems, adequate ventilation of enclosed buildings is advised, and controls consist of maintaining dry conditions in the manure to reduce ammonia discharge. Ammonia is, therefore, classified as an intramedia pollutant.

Environmental Impact

Ammonia and ammonium salts are not important man-created air contaminants. Ammonia is an important raw material in the fertilizer and organic chemical industries and in the manufacture of nitric acid by the oxidation process. Its recovery is a matter of fundamental importance in the economical operation of such processes and in the manufacture of gas from coal. Ammonia may also have harmful effects on farm animals kept in enclosed areas under moist conditions since this causes increased ammonia release from the manure.

ETHYLENE

Intermedia Relationships

Controls consist mainly of safe handling and thus ethylene is classified as an intramedia pollutant.

Environmental Impact

Ethylene in high dilution causes injury to leaves of sensitive plants. As little as 0.1 ppm ethylene in the air causes epinasy in sweet peas and tomatoes, and 0.05 ppm in buckwheat and sunflowers. Injury by ethylene has been observed in greenhouses with leaking gas lines.[18] It is not a major air pollutant nationally.

INTRAMEDIA OR LESSER INTERMEDIA WATER POLLUTANTS (SINGLE MEDIUM)

Thermal pollution is classified as a lesser intermedia pollutant because of the limited areas in which it is critical while pathogens, pesticides and liquid hydrocarbons are classified as major pollutants which are basically intramedial. Metallic salts and oxides chlorides, and surfactants are all classified as lesser intramedia pollutants. Information concerning these lesser pollutants is very limited and it is not possible to develop accurate national discharges for them. Therefore, the discussions of these pollutants will include only a brief paragraph concerning the intermedia relationships and one concerning the environmental impact of the pollutant. No flow charts have been developed for these lesser pollutants and the discussions will explain the reasons for classifying them as such. In general, the criteria used are those presented in "Major vs. Lesser Pollutants," Section III.

THERMAL POLLUTION

Intermedial Relationships

Figure 16 illustrates the intermedial relationships for thermal pollution. Heat may be transferred from air to water or water to air. Since thermal pollution is more serious in water, most conscious controls transfer heat from water to air.

When water is used as a coolant in an industrial process, this water must be cooled for reuse or for discharge to receiving waters. The cooling is usually achieved by spray chambers or cooling towers which transfer the heat to the air.

It is also possible to transfer heat from air to water, as in the instance of a spray chamber in an air conditioning system. Cooling systems can have a significant intermedial impact. Evaporation loss is about 1 percent for each 10°F drop in temperature, whether this is through a pond or tower. Windage losses are about 1.0 to 1.0 percent for atmospheric towers, and 0.1 to 0.3 percent for mechanical draft towers.[123] In plants with other pollutants in their emissions, the mist may combine with SO_x and other air pollutants to create corrosive acids.[334] As an example, NO_x may form nitric acid upon contact with the mist. Corrosion and algal growth can cause severe problems in areas around the cooling towers. Salt build-ups and corrosion can also be severe within the cooling system.

Environmental Impacts

The term thermal pollution refers to the waste or excess energy in the form of heat which is released to one of the media from a source. Whether or not this heat is actually a pollutant depends upon its environmental effect. Since heat or energy is usually the primary product of thermal pollution sources, its waste is a direct result of the producer's inefficiency.

Since a water body, especially a stream or small river, has a small volume relative to that of the atmosphere, temperature changes due to heated discharges seem more pronounced in the water. Yet one British thermal unit will change 0.016 cu ft of water

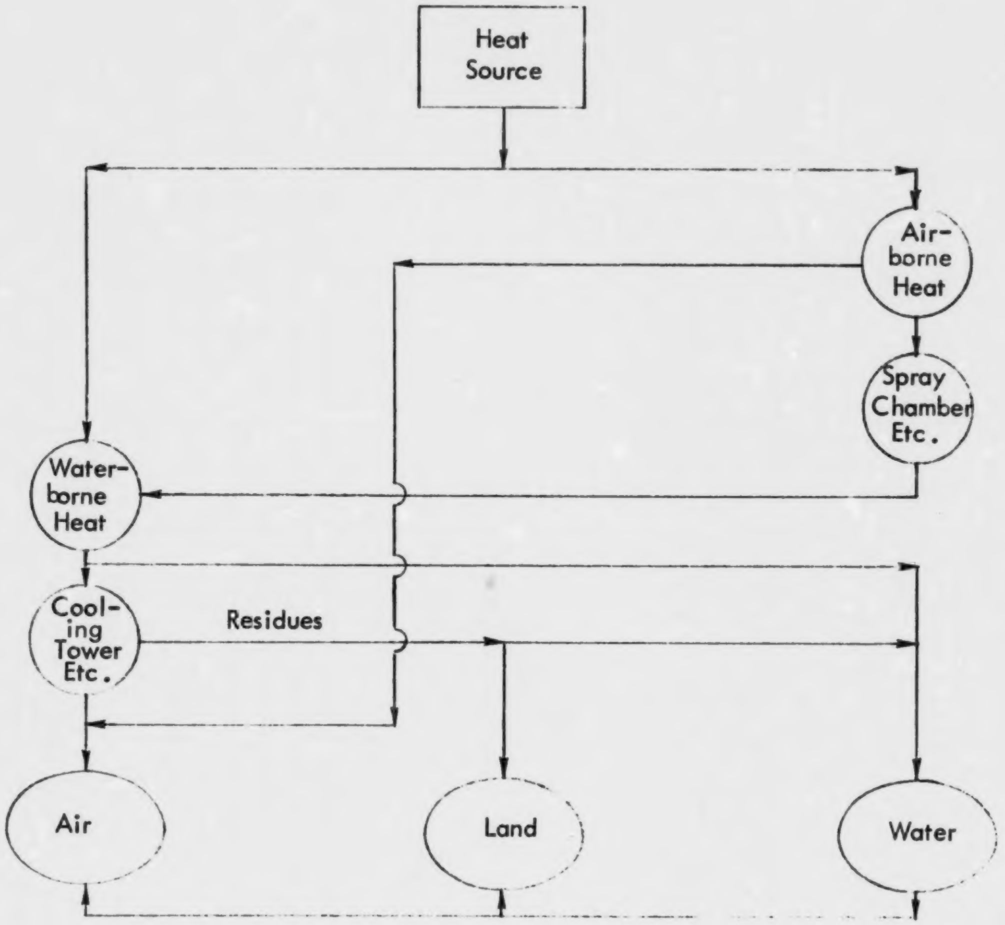

Heat Source
Air-borne Heat
Spray Chamber Etc.
Water-borne Heat
Cool-ing Tower Etc.
Residues
Air
Land
Water

FIGURE 16
INTERMEDIA FLOW CHART
THERMAL POLLUTION

(1 pound) one degree Fahrenheit. The same amount of heat will produce the same change in temperature in 52 cu ft of air at standard pressure and temperature. This is a volume ratio of 1 to 3250.

Abnormal temperature of a water body may adversely affect or kill its existing life forms. For example, a fish might hatch too early in an artifically warmed stream and find an inadequate food supply because the food chain depends on plants whose abundance depends in part on the length of day rather than the temperature. A fish may be unable to compete in 75° to 80°F water if it is accustomed to 70°F water.[210] Because of the large volume and good mixing action of the atmosphere, great amounts of energy can be discharged without a noticeable temperature change.

An experimental use for the heated water from cooling systems has been to heat greenhouses in cold areas to provide one or two extra crops a year. This experiment has worked well in Romania, where it was used for economic rather than ecologic reasons. In the warm months when the water is not needed for the hothouses, an alternate means of treatment would be needed.[295]

Major Sources

The major sources of excess heat are stationary sources, such as power plants. Lof and Ward[170] have estimated that 80 percent of all water used by industry is for cooling purposes and that by 1980 approximately 10 percent of all river and stream water in the United States will be used for cooling.

Treatment Processes

The cooling systems which produce the heated wastewater can be classed in two broad categories, once-through(or single-pass)and recirculating systems. Very often, the single-pass system receives no treatment for transferring heat to the air. However, one method of cooling presently in use for these single-pass systems is the use of a pond or canal connecting the source with the receiving water. This provides a means of heat loss primarily through evaporation.[244]

There are several methods of removing heat from recirculating cooling water systems. The simplest method, where low-cost land is available, is the use of ponds. The water may be discharged directly into the pond, but is often sprayed into it, providing more surface-to-air contact and more rapid dissipation of the heat. Where land is not available for ponds, cooling towers may be used. A portion of the water evaporates bringing the remaining water down to the desired recirculation temperature. To lower the water temperature 10°F, approximately 1 percent of the water must be evaporated. However, where the air temperature is much less than that of the water, the evaporation loss may be reduced. Other volume losses such as from wind or leaks raise the total make-up water requirements somewhat. Ordinarily, a recirculatory system will run on about 2 to 4 percent of the water volume requirements of a once-through system.[170]

PATHOGENS

Intermedial Relationships

Figure 17 depicts the intermedial relationships for pathogens. Man-controlled intermedia transfers of pathogens include water or air or land transfers. While humans can affect air,contamination they do not directly transfer pathogens from air to water or vice-versa.

Human fecal matter is major source of pathogenic organisms in the environment. Infection of humans can occur by direct contact with contaminated fecal matter or indirectly by contact with water polluted by feces. Air contact with pathogens is also possible, although not as probable as other contact mechanisms. Vectors are another route by which humans can come in contact with pathogens. It is possible that pit toilets,cesspools and septic tanks can contaminate water supplies by percolation and leaching when these sources are located near ground or surface waters.

Treated sludges from sewage treatment plants contain pathogens and should be treated or disposed in a hygienic manner. Incineration of sludges destroys most pathogens,while unincinerated sludges disposed to the land are potentially capable of contaminating adjacent waters. Exposed sludges may also present a contact source for the various vectors.

Aerosols containing pathogens can be formed directly from fecal matter or polluted water. The contaminated aerosols are viable for a short period of time, but the contained pathogens are capable of polluting as the aerosols settle out with natural precipitation.

Environmental Impact

The pathogens in human fecal matter have been widely documented. In a review of the literature, Hanks[173] has identified the disease agents as described below.

Bacterial Infections Typhoid fever, paratyphoid fevers A and B, cholera, and shigellosis are enteric bacterial diseases in man. The pathogenicity of E. coli organisms is not entirely clear.

The viability in the environment of various bacterial agents is summarized as follows: Shigella can remain viable in tap water for as long as 6 months, in sea water for 2 to 5 months, and in ice for 2 months. Soiled clothing can maintain the organism for several days. Shigella can be destroyed by pasteurization and chlorination. The viability of Salmonella typhi is from 2 to 3 weeks in groundwater, 1 to 2 months for fecal matter in privies, and at least 3 months in ice or snow. Salmonella and Shigella can be killed by pasteurization at 66°C for 30 minutes or by chlorination with 0.5 to 1.0 mg/l free chlorine[174].

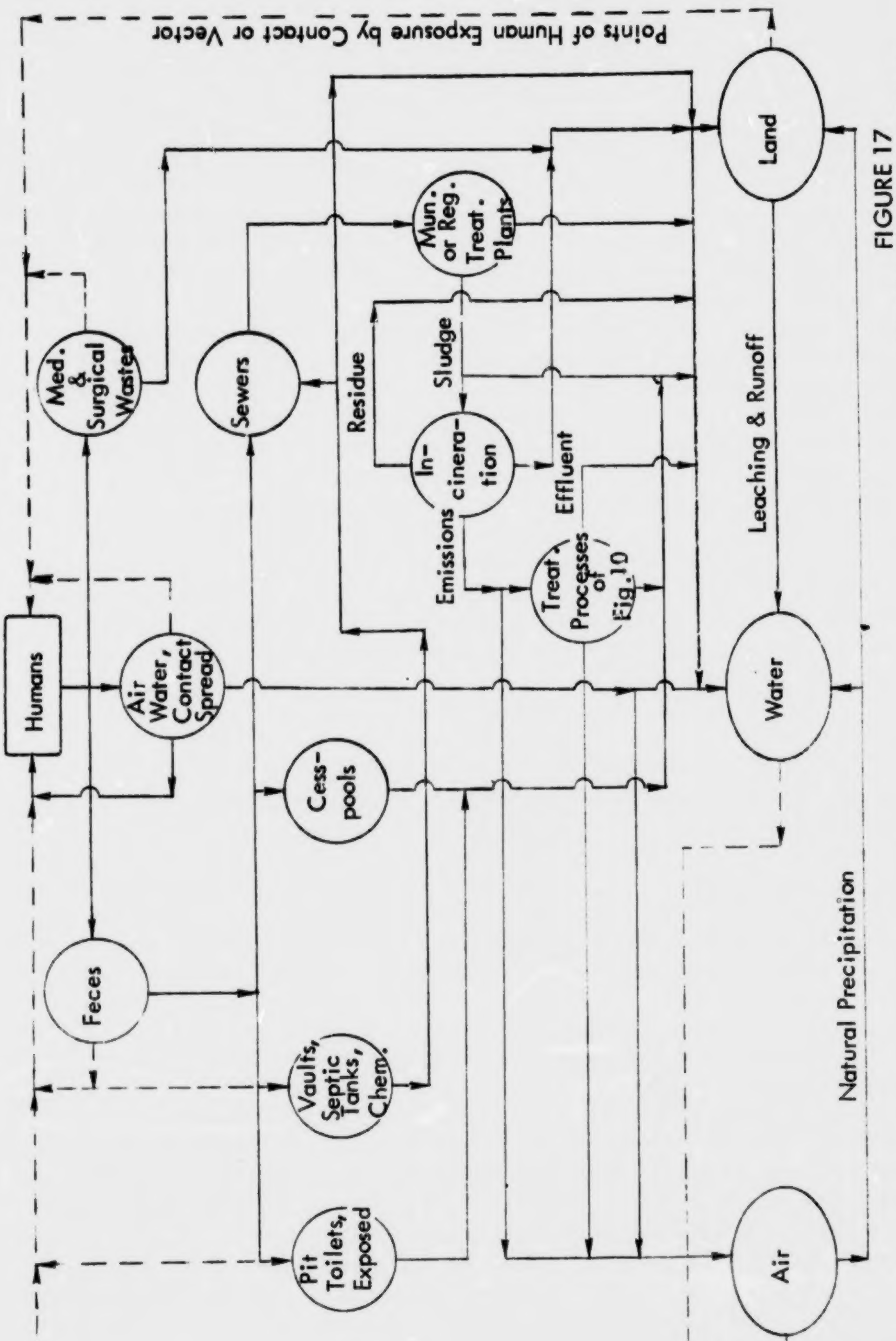

Points of Human Exposure by Contact or Vector
Humans
Feces
Med. & Surgical Wastes
Air Water, Contact Spread
Sewers
Cess-pools
Pit Toilets, Exposed
Vaults, Septic Tanks, Chem.
Mun. or Reg. Treat. Plants
Residue
Sludge
In-cinera-tion
Emissions
Effluent
Treat. Processes of Fig. 10
Leaching & Runoff
Natural Precipitation
Land
Water
Air

FIGURE 17
INTERMEDIA FLOW CHART
PATHOGENS

Viruses The main viruses of importance in human excrement are poliomyelitis, Coxsackie and infectious hepatitis. According to Clarke and others,[175] in the preceding 15 years, 70 new enteric viruses have been recognized in human feces. The waterborne disease danger to the population will increase if a multiplying population contaminates more water supplies, and thus produces a greater environmental degradation.

Poliomyelitis virus has been shown to be excreted in feces as long as 2 to 3 months after onset of disease. Coxsackie and ECHO viruses can be passed into the feces for several weeks or months and are extremely viable in sewage. Virus isolates have been found in sewage all over the world, indicating that they are able to withstand the extreme temperatures found in diverse geographical locations.

Most viruses may be destroyed by temperatures greater than 100°C and less than 0°C. Chlorination can prevent the spread of infectious hepatitis, and most adenoviruses and enteroviruses are destroyed after remaining a period of 10 minutes in contact with free chlorine residuals of 0.3 to 0.5 mg/l.

Recently the number of pathogenic and non-pathogenic strains of viruses isolated from feces has greatly increased. These agents are thought to be universal, and the threat of disease spread via the alimentary tract remains of concern to epidemiologists, particularly in areas where protective measures are lax.[176]

Protozoal Infections The most significant disease agent in this class is Entamoeba histolytica which is the only specie found in the United States. Cysts of Entomoeba histolytica are destroyed by dessication, sunlight and heat.

Helminthiasis This type of pathogenic organism refers to worm infestations of human fecal origin. The most common are the tapeworms including Dipyllobothrium latum (fish tapeworm), Taenia saginata (beef tapeworm), Taenia solium (pork tapeworm) and Enterobius vermicularis (pinworm). Also included are (the human roundworm) Ascaris lumbriocoides, (the whipworm) Trichuris trichiura, and the human hookworms Necator americanus and Ancylostoma duodenale.

Vectors Pathogenic organisms in human feces are transmitted to man via several pathways. Either direct or indirect contact with infected fecal matter must occur before an infection can appear. The five major disease routes are identified as: vector-borne, soil-borne, direct contact, water-borne, and air-borne.

A major mode of disease transmission is by direct contact with biological vectors (houseflies, cockroaches and domestic mosquitos). The diseases transmitted by these vectors are amoebic dysentery, cholera, coxsackie diseases, infectious hepatitis, poliomyelitis, shigellosis, typhoid and paratyphoid fever and worm (helminth) infections.

The method of transmissions of several fecal waste associated diseases will be discussed. The spread of amoebic dysentery is provided by direct contact with fecally contaminated food, direct contact with feces or by water transmission. Cholera is not found in the United States today, but it is still a public health hazard in undeveloped countries. Cholera can be transmitted through contaminated water, by direct contact or by flies that have had direct contact with human excreta containing the organism. The methods of transmission of Coxsackie and polio virus are still vague, although these viruses are known to exist in human feces and flies having access to infected feces. Infectious hepatitis is transferred chiefly through direct contact or fecal contamination of water supplies. There is evidence that some municipal sewage treatment plants do not effectively remove the hepatitis virus. This is substantiated by higher hepatitis morbidity in communities where treated sewage is discharged into stream estuaries.

The primary route of typhoid propogation is the human typhoid carrier. Typhoid infected fecal waste has been associated with the direct contamination of milk or food not properly protected, and of well water and other water supplies by septic tanks and privies.

Worm infestations of human feces is common. Sewage sludges have been found to contain eggs of pathogenic helminths. The use of untreated sewage sludge as soil conditioners and fertilizers should be avoided to protect against worm infestations through direct contact.[173]

Main Sources

The main sources of pathogenic pollution are human wastes. These include municipal sewage, exposed pit toilets, septic tanks, and cesspools. The presence of pathogens in human feces, sewage sludge, or septic tank pumpings discharged to the environment can be a basic causitive agent in communicable diseases. Exposure to fecal waste is a result of inadequate liquid and solid waste management, including recycling processes. Approximately one-third of the nation's homes are served by private sewage disposal systems, the majority of which are septic tanks. Municipal waste treatment plants receive the liquid waste from the rest of the population. The types of pathogenic organisms associated with municipal sewage treatment plant discharges and septic tank pumpings are identical although treatment plant discharges usually contain far fewer pathogenic organisms than do raw septic tank pumpings.

Alternatives

The following discussion explains in detail the relationships illustrated in Figure 17 .

Central Sewage Treatment and Septic Tanks A higher concentration of pathogens occursin septic tank pumpings than in aerobically treated sanitary wastes because the treatment is significantly less in septic tanks than in central treatment plants. Laboratory analyses for Coxsackie and polio virus have shown that between 90 to 98 percent of these viruses can be removed by the activated sludge process. Primary sewage treatment processes which are similar to the septic tank process are relatively ineffective.[175] The removal of viruses by the activated sludge method appears to be the most effective. However, disinfection may be the only way to insure virus-free effluents. If chlorination is used for disinfection, and this is the widely accepted method at present, substantial residuals of free chlorine must be present to effect the destruction of pathogenic organisms.[177] Heat-dried sludge has been[178,179] considered to be free from disease agents.

Human health problems may arise through the exposure to inadequately treated sludge. Occupational exposure to pathogenic organisms may exist for agricultural workers who use sludges as fertilizers. Agriculture use of sludges may also contaminate surface waters through runoff.[180, 181]

Septic tank pumpings can be treated at central sewage treatment systems. Discharging septic tank pumpings directly into a sewage treatment facility may cause odors and thereby influences the acceptability of such practice.

Landfills An alternative approach is to discharge septic tank pumpings directly to a sanitary landfill. Two factors must be recognized concerning this method of disposal. Septic tank pumpings contain a substantial proportion of raw sewage and have a considerably higher concentration of pathogens than digested sludge; septic tank pumpings have a lower solids content and, therefore, may have a greater tendency to runoff and leach into groundwater. Because of their septic condition, the odors produced make this method an unpleasant operation.

The health hazard can be minimized if a properly located, and adequately designed and operated landfill is employed. Landfills should generally be sloped to provide runoff away from surface waters and to minimize percolation. They should also be located to avoid contamination of groundwaters. Mixing liquid sludge with dried sludge can also inhibit the leaching process.[182] Similarly, admixing liquid sludge with solid waste can prevent leaching and is beneficial to the landfill.

Most pathogens die naturally as they are filtered by the soil before or after reaching groundwater systems. E. coli has been shown to be viable for 31 months in polluted groundwater.[183]

The possibility of pathogens leaching into ground or surface waters from sanitary landfills does exist. An average of 5 to 10 million bacteria and fungi and 740,000 coliform bacteria have each been measured in a gram of solid waste.[185] Leachates have shown concentrations as high as 9,500 coliforms per ml,[186] and coliform counts (MPN) up to 100,000 per ml have been measured experimentally.[187]

E. coli in fresh refuse has been found in densities over 5,000 per dry weight. This value is reduced to 0 to 100 per gram after a period of 3 years. Corresponding values for Streptococcus fecalis are 2,500 and 0 to 60 organisms per gram of dry weight, respectively.[188]

While pathogenic organisms may be present in leachate, a public health hazard does not necessarily exist. Soils have the capability of filtering out pathogens in leachate, and it has been reported that coliforms are seldom found below the 4-foot level and never below 7 feet, even in highly permeable soils.[189] If bacteric happen to penetrate the groundwater system, it is reported that the bacteria will not survive more than 50 yards in the direction of groundwater flow.[190]

One study has shown that shallow landfills may leach the bulk of pollution in a relatively short period of time and thereby exceed the dilution capacity of the receiving groundwaters.[187]

Odors are a major nuisance accompanying septic tank pumpings and anaerobically digested sludge. These odors can be an annoyance to residents near treatment plants or landfills. Accompanying the odors may be a fly control problem resulting in an increased risk of disease through vector transmission. Plowing and disking of land after sludge application will control fly and odor problems.[179]

Fly problems are usually associated with open dumps or inadequately covered landfills. Flies may migrate up to 5 miles from an open dump and impose a disease threat on residents within that radius. Disease transmission via rodents and other biological vectors also make open dumps unacceptable. A properly maintained sanitary landfill eliminates rodents and flies by removing the food supply and shelter with a compacted soil cover. Six inches of compacted earth will prevent the emergence of flies, although flies can emerge through 5 feet of uncompacted soil.

At present some communities have reservations about discharging septic tank pumpings directly into landfills and have passed legislation prohibiting the discharge of untreated sludges at landfills.[191] A survey of California disposal sites showed that 37 percent of the open dumps and 44 percent of the sanitary landfills were operating under ordinances prohibiting the discharge of sewage treatment residues.[192]

Pathogenic organisms are a major national intramedial water pollutant but are not normally a significant intermedial air pollutant except under certain local conditions.

PESTICIDES

Intermedial Relationships

Figure 18 illustrates the intermedial relationships for pesticides. Most intermedial flows stem from agricultural application of pesticides and are natural processes. Pesticides are therefore classed as a major intramedial pollutant rather than a major intermedial pollutant. Waste effluents from pesticide manufacturing operations are not the major source of pesticide pollution. These effluents however, can be treated effectively with activated carbon. Discharge is frequently directly into sewer systems and sometimes, unfortunately, to nearby surface waters. Sewage treatment plants and the activated carbon treatment both create residues. The carbon can be regenerated, incinerated or disposed to the land. Sewage sludges may be either incinerated or disposed to the land. Incineration of these materials can produce emissions containing pesticides.

While agricultural and domestic application of pesticides are directed primarily toward the land, air application of pesticides creates uncontrollable aerosols. Winds and other climatic conditions affect whether air-applied pesticides will fall as intended or drift to adjacent lands and waters. Pesticide residues on land can be transported to adjacent waters via leaching, irrigation and storm runoff. Chlorinated hydrocarbons are highly volatile and readily transfer to the air through evaporation. Pesticides in the air resulting from industrial emissions, sewage sludge incineration, industrial, agricultural, and domestic applications eventually return to the land or waterways through natural fallout and precipitation. Herbicides are normally classed with pesticides.

Environmental Impact

Many types of pesticides are used for such purposes as control of insects, weeds, fungi and rodents. After application the most persistent of the pesticides are the chlorinated hydrocarbons, also known as the organochlorine pesticides. Attention is given here to the chlorinated hydrocarbon pesticides (DDT, chlordane, aldrin, dieldrin, endrin, heptachlor, toxaphene, methoxychlor) because of their reluctance to undergo chemical and biological degradation. Because of this persistence, the occurrence of the chlorinated hydrocarbon pesticides has the greatest impact on the environment. Since these compounds persist a long time in the environment, they may be transferred by wind, water, animals and food to places far from where they were applied. This mobility of pesticides tends to contaminate non-target areas and living species. The result is that localized areas may be treated with pesticides, but subsequent spreading of these small amounts may spread to much larger areas and affect wildlife species which are sensitive to low concentrations of pesticides.

Pesticides are a unique source of pollution since usually they are intentionally introduced into the natural environment. Pesticides reach the environment by direct application to the land for agricultural purposes. Also pesticides inadvertently enter the environment from industrial discharges, accidental spills, and from domestic sources such as home garbage disposals. Herbicides have the similar impacts as pesticides.

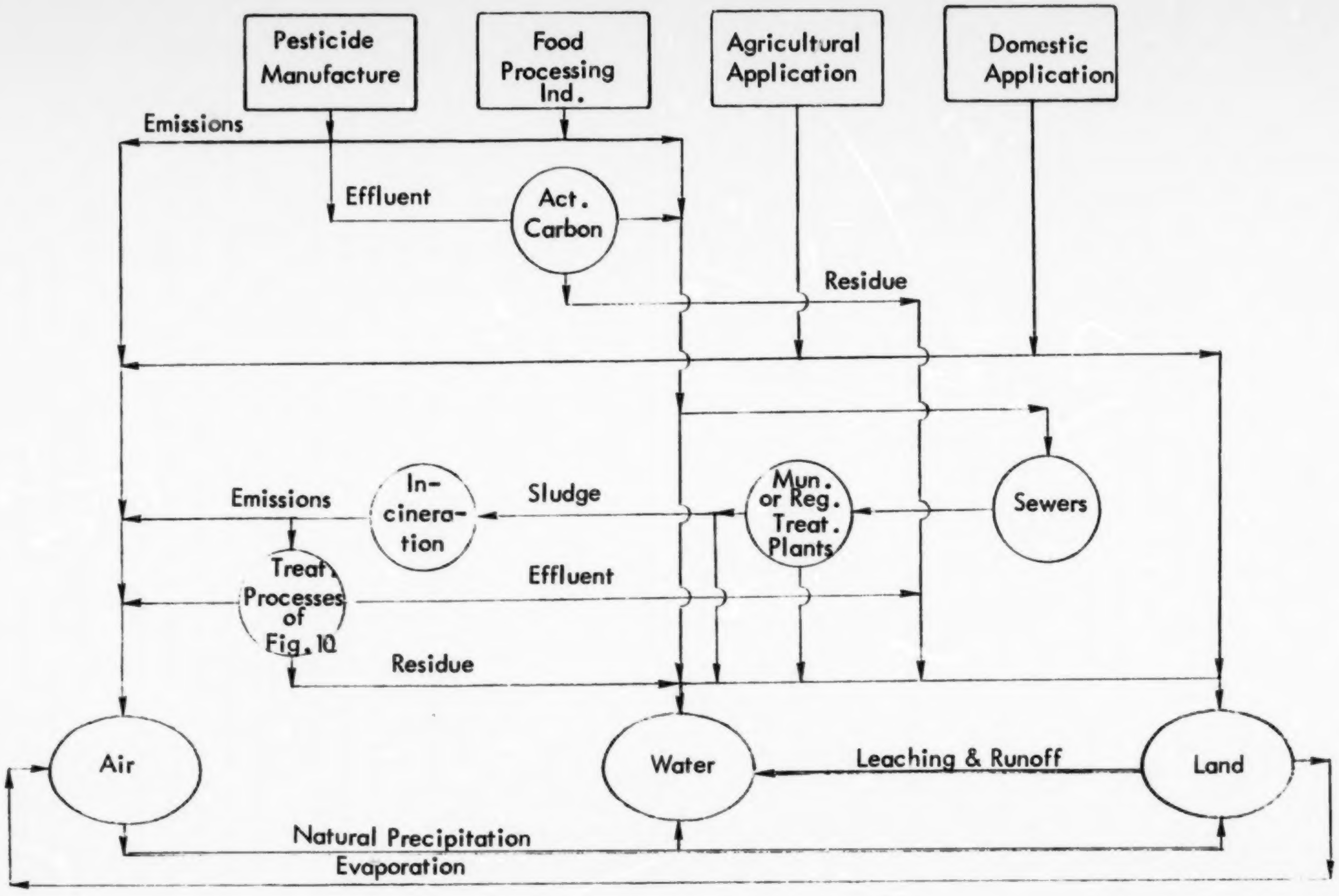

Pesticide Manufacture
Food Processing Ind.
Agricultural Application
Domestic Application
Emissions
Effluent
Act. Carbon
Residue
In-cinera-tion
Sludge
Mun. or Reg. Treat. Plants
Sewers
Emissions
Treat. Processes of Fig. 10
Effluent
Residue
Air
Water
Leaching & Runoff
Land
Natural Precipitation
Evaporation

FIGURE 18
INTERMEDIA FLOW CHART
PESTICIDES (HERBICIDES)

Main Sources

Pesticides in the Soil Pesticides are applied directly to the soil for agricultural purposes. Repeated applications may create accumulations. These pesticide residues in the soil are of concern since they may reach man and wildlife through uptake from soil by consumable crops, by leaching into water supplies, by volatilization into the air and by direct contact with the soil. The factors which affect pesticide persistence in the soil are: (1) pesticide molecular configuration, (2) pesticide adsorption, (3) organic content of the soil, (4) soil moisture and temperature, (5) uptake by plants, and (6) leaching of pesticides from soil by water.[193]

The chlorinated hydrocarbon pesticides are extremely hydrophilic, making them highly insoluble in water. The solubility of a substance is inversely proportional to its affinity for adsorption. Chlorinated hydrocarbon pesticides are therefore highly capable of being adsorbed and concentrated on soils and finely divided clays. The adsorbed pesticides can then be carried with the soil and clay particles into natural waters. Surface runoff after either rainfall or irrigation may transport particles to which pesticides adhere or the water may leach the pesticide from the soil particles.[194]

Chlorinated hydrocarbon pesticides are more persistent in soils where the organic content of the soil is high. Chlorinated hydrocarbons are highly resistant to biological attack so their retention in soil is not affected appreciably by the microorganism concentration.[195] Adsorption rates and soil microbial activity are both affected by soil temperature and moisture. High moisture content and temperature enhance the degradation process and increases the amount of volatilization which occurs. Volatilization is a major pathway of loss for the chlorinated hydrocarbons. The process involves the desorption of the pesticide from the soil, diffusion upward to the soil surface, and then volatilization of the compounds into the atmosphere. Rates of loss by volatilization are related to the vapor pressures which, for chlorinated hydrocarbons are relatively low. However, the degradation products of lindane and DDT have much higher vapor pressures than their parent compounds, which means that the presence of these degradation products in significant amounts is an indication that volatilization of degradation products provides a major pathway for loss of some organochlorine insecticides from soil.[196]

Plants can absorb pesticides from the soil, concentrating the residue within their structure. This mechanism constitutes a potential exposure hazard for man and animals when the absorbing plants are edible or forage crops. Experiments in Great Britain have shown that plants can also absorb organochlorine residues from the surrounding air.[197]

Pesticides in the Water The major pathways by which pesticides reach the water environment are through direct application to surface waters, indirect application during treatment of adjacent areas, percolation and runoff from treated agricultural or forested lands, and by the discharge of certain wastewaters.

Most chlorinated hydrocarbon pesticides reach the aquatic environment attached to soil or clay particles because of the hydropholic nature of these compounds. Usually these particles settle to form the bottom sediments of streams and lakes.[199] Under certain conditions, a portion of the adsorbed pesticides can be desorbed directly into the water where they are maintained by a dynamic adsorption-desorption equilibrium system. Consequently, pesticide desorption provides a continuous supply of toxic material to water and creates many serious water pollution problems.[194]

Pesticide residues are concentrated by soil and clay particles and also by microorganisms. It is possible through these associations for pesticides to reach ground and surface waters although the extent which the quality of ground water is threatened is not as well established as that of surface waters. Factors of paramount importance in the consideration of ground water pollution by pesticide residuals in soil are the amount of residue, the solubility of the pesticide in water, the amount of infiltrating water, and the adsorptive rate and capacity of the soil. One study has concluded that dieldrin could not be transported through soils into subsurface waters in significant amounts by infiltrating waters.[195] A period of several hundred years was determined to be the time required for dieldrin to be transported in solution at a residual concentration of 20 ppb to a depth of 1 foot in natural soils. It appeared from this study that residues of dieldrin applied on the upper layers of soil do not threaten the quality of ground water at the assumed permissible concentration of 20 ppb. Studies have shown that dieldrin residues in soils have been detected up to 7 years after application, and 72 to 90 percent of the residues remain in the top 3 inches of the soil. Trace quantities of dieldrin have been found as deep as 9 inches in soil. Dieldrin is used in experimental studies because it is considered to be one of the most persistent of the pesticides in soil. Another study revealed that after 10 years, 60 to 75 percent of residual DDT remained in the top 12 inches of the soil.[200] The movement of DDT to lower soil depths was attributed to top soil being washed by rainfall into large vertical cracks in the ground. Even though these studies show that pesticides do not usually migrate to great depths in soils, incidents of pesticide contamination of ground waters have been documented.[201,202] During one incident in 1951, crops were damaged when irrigated with well water contaminated with the herbicide 2,4-D. A nearby 2,4-D manufacturing plant had discharged its wastes into lagoons from 1943 to 1957. It had taken between 7 and 8 years for the pesticide to migrate 3.5 miles and eventually contaminate an area of 6.5 square miles. The herbicide 2,4-D was also reported to have been inadvertently dumped into a sewer. The waste reached underground strata which supplied well water to Montebello, California. The taste and odor of the herbicide was evident for over 5 years.[193]

Pesticides in the Air The application of pesticides to land for agricultural uses is most generally accomplished by air. About 80 percent of the pesticides are applied by aircraft.[193] An understanding of the ways in which air and pesticide particle size influence pesticide applications is necessary to apply pesticides without affecting non-target areas. Studies have been made to determine the correlation between pesticide particle size and drift from the intended target area.[204,205,206] As expected, these studies indicate the greatest potential non-target contamination hazard resulting from drift occurs with smaller diameter particles. The control of drop size to provide larger drops and reduce the drift potential, results in a decrease in coverage by spraying.

Coverage increases as drop size decreases. Although large drops hit the target area more frequently, the extent of coverage is less. A compromise is necessary to minimize drift and obtain a good coverage. A wide distribution of drop size is inevitable with commonly used spray equipment, and the measurement of wind and atmospheric conditions is therefore important in determining the safety of a pesticide application. In the case of chlorinated hydrocarbon, it is not unusual to find 50 percent or more of the applied pesticide unaccounted for where a material balance of the treated area is made immediately after application. Most of the unaccounted portion is dispersed in the air as fine particles or aerosols, or carried to adjacent areas.[202]

Pesticides can also enter the air when soils contaminated with pesticides are subjected to erosion by wind. With appropriate conditions of soil, moisture, humidity and wind, pesticide residues from soils can enter the air and be transported great distances. In the air DDT can be transported as vapor, tiny crystals or a mixture with dust particles. One study traced DDT and other pesticides in a dust storm from West Texas to Cincinnati. The mobility of pesticides in air is also demonstrated by the fact that Antarctic ice and snow contain thousands of tons of DDT residues transported there through the air.[207]

Pesticides in Industrial Wastes The industrial wastes from the pesticide manufacturing and food processing industries usually may not be safely discharged directly to the environment. The pesticides in liquid effluents require treatment to remove the danger to aquatic life. Settling basins are used to allow time for gravity removal of some solids; solid and liquid sludge wastes can be incinerated, but the scrubbing of stack gases is needed to remove contained pesticides. The deep well disposal of pesticides is only practical when the geological characteristics of the area are sufficient to protect against ground water contamination.[193] There is the possibility that pesticide wastes in the disposal areas of pesticide manufacturers will leach from these sites into waters and soils for hundreds of years.[202]

Treatments

Industrial waste effluents can be treated to remove large concentrations of pesticides. Pesticide adsorption by activated carbon has been shown to be the most effective treatment for reducing high concentrations of pesticides from water. The removal of low level pesticide contamination is much more difficult to control, and evidence indicates that current conventional water treatment methods are not effective.[193] Sludges from pesticide related industries and municipal sewage treatment plants can contain significant amounts of pesticides. Incineration of these sludges will produce pesticide emissions which require further treatment to avoid discharge to the atmosphere.

METALLIC SALTS AND OXIDES

Intermedia Relationships

The main controls for salt compounds in water are evaporation, dialysis, ion exchange, and some other miscellaneous methods, all of which are intramedial.[324] These methods all separate the salts from the water, leaving salt in a solid form. These residues can then be used or disposed to land. In either case no air-to-water or water-to-air transfer results. In some cases salts can result from an intermedia transfer from air such as from the precipitation of airborne metallic oxides. Since further treatments are intramedial, metallic salts and oxides are classed as intramedial pollutants.

Environmental Impact

The most significant impact of metallic salts and oxides is the salinity produced in water. Hydroxides can, however, produce an impact through their influence on acidity. Most metallic oxides are in a transitory state in water although a few do precipitate to add to the suspended solids. Most discussions of dissolved solids in the literature relate only to salinity.

The most important effect of salinity or total dissolved salts in irrigation water is the toxicity to plants. Of course, different plants have different tolerances to salt concentration. A prime example of the effects of salinity is shown in the Monterey area where the intrusion of salt water from the ocean has forced the change from lettuce, as a major crop, to artichokes, which have a greater salt tolerance. For human consumption, the recommendation of the U. S. Department of Health, Education and Welfare is that drinking water does not contain more than 500 mg/l and preferably less than 200 mg/l of total dissolved solids.[321] Salt buildups also affect the functioning of industrial water reuse systems and cause increased maintenance expenditures.

CHLORIDES

Intermedia Relationships

Controls for chlorides are achieved by demineralization, either by ion exchange or by using membranes. These controls are intramedial.

Environmental Impact

Chlorides may be a problem in such diverse areas as sewage treatment plants[315] and irrigation water.[210] In sewage treatment plants, high chloride concentrations may interfere with plant operation, especially with the activated sludge process.[315]

Most agricultural crops will be adversely affected by high salinity before they are affected by chloride *per se*; however, some fruit crops are harmed by very low concentrations of chlorides.[316] Some crops which are not necessarily damaged by high chloride concentration are damaged by high salt concentration.[210]

SURFACTANTS

Intermedia Relationships

A number of treatments have been proposed for the removal of surfactants from water. These include foaming, aeration, flotation, coagulation, flocculation, adsorption on carbon and other inert matter, biological treatment, and treatment by resins.[318] These treatments do not create water-to-air transfers of pollutants and are not intermedial.

Environmental Impact

Surfactants are not as great a problem as they once were when the detergents used were largely non-biodegradable.[317] In sewage treatment it has been found that surfactants interfere with anaerobic sludge digestion.[319] Also, there may be a synergistic action between these substances and certain pesticides such as DDT.[320]

LIQUID HYDROCARBONS

Intermedia Relationships

Hydrocarbons in liquid form are significant water pollution factors in certain areas of the United States. The intermedia relationships are shown in Figure 19. Liquid hydrocarbon pollution of the sea and of lakes and waterways can severely damage fish, other animal, and plant life. Spills from oil well drilling and operation, from pipeline breaks, from offshore oil drilling, and from the sinking or washing down of oil tankers are the major sources.

Environmental Impact

Solutions to these problems lie in greater safety precautions, moratoriums or greater controls on offshore oil drilling, and stricter enforcement of laws controlling ocean dumping from ships. None of these is intermedial.

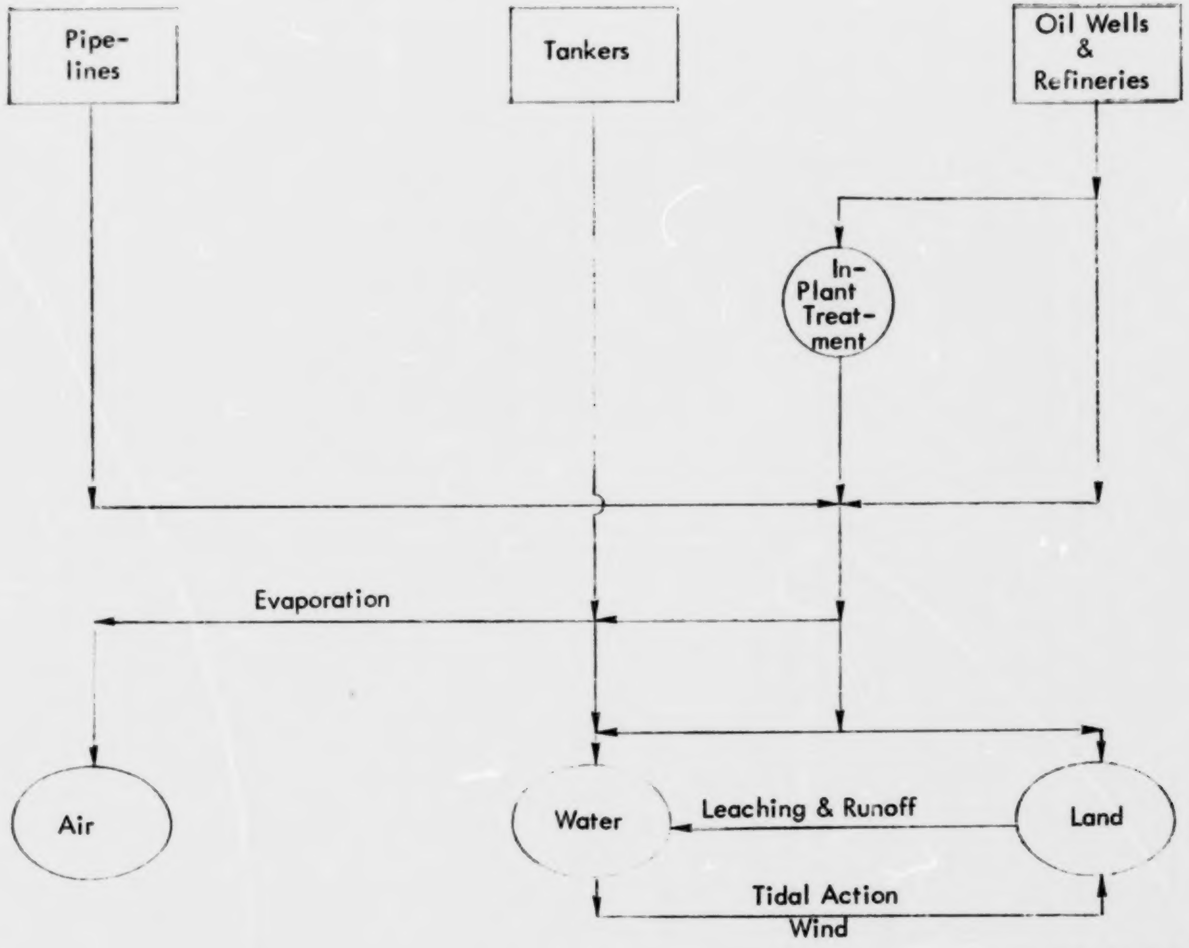

Pipe-lines
Tankers
Oil Wells & Refineries
In-Plant Treatment
Evaporation
Air
Water
Land
Leaching & Runoff
Tidal Action
Wind

FIGURE 19
INTERMEDIA FLOW CHART
LIQUID HYDROCARBONS

SECTION VI
TREATMENT SUMMARIES

This section summarizes the information on treatment methods that was included in the discussions of pollutants in Section V. Air and water treatment methods are discussed separately. A list of alternative unit processes is given for air and water treatment for the various industries and includes quantified intermedia effects where they are known. The treatment processes will be discussed with respect to pollutants controlled, costs, residue quantities, and residue effects.

Air Pollution Treatments

Table 14 provides a summary of the various air pollution treatments, the pollutants they affect, and the intermedia transfers created. The residues created are in the same form as the pollutants removed unless otherwise indicated.

Costs of Treatment and Residue Disposal

A difficulty exists in accurately defining treatment costs without plant size distributions, plant lay-outs, and other specific plant data. A set of equations was developed by Edmisten and Bunyard in an attempt to standardize cost presentations for air treatment methods.[258] These equations provide a reasonable summary of the factors that affect air pollution treatment costs and how they interrelate. They are presented in Table 15 .

Operating and maintenance costs vary widely in proportion to capital costs. In particulate control, combined operating and maintenance costs may be as low as 15 percent of the annualized total cost for dry centrifugal collectors and electrostatic precipitators,or as high as 90 percent for high efficiency wet collectors.[258] Table 16 lists some typical capital costs for particulate control methods.[258]

Operating cost parameters may vary as follows: maintenance costs, from $0.025 per cfm for dry centrifugal collectors to $0.10 per cfm for thermal afterburners; liquor for wet scrubbers, from $0.01 to $0.05 per gallon; and electrical costs, from $0.005 to $0.02 per kilowatt (Kwh). The pressure loss and resultant horsepower and electricity costs differ for each method. It is, therefore, necessary to make individual analyses to identify a "best choice" control method from an economic standpoint. Typical pressure losses vary from insignificant for electrostatic precipitators, to one inch of water for afterburners, to ten inches of water for wet scrubber fans. The electrical costs therefore vary considerably,as do installation costs. Edmisten and Bunyard gave sample calculations for three typical controls.[258] They are presented in Table 17. In spite of their higher electrical costs, it should not be assumed that wet scrubbers are necessarily unfeasible because they can control pollutants other than particulates and also electrical costs vary considerably. Assuming electrical cost reduction of 50 percent, incremental cost savings per year would be $26,250 for wet scrubbers, $3,870 for the fabric filters, and only $1,760 for the electrostatic precipitators. This significantly reduces the cost differential.

TABLE 14
INTERMEDIA TRANSFERS IN AIR TREATMENTS

	AIR POLLUTANTS								INTERMEDIA TRANSFERS		
Treatment	Oxides of Nitrogen	Oxides of Sulfur	Carbon Monoxide	Hydrocarbons - Particulate	Hydrocarbons - Gaseous	Particulates	Radioactivity	Thermal	Air	Water	Land
Water Scrubbing		●		●		●		●		SS, TDS, H_2SO_3, H_2SO_4 Pathogens, Heat	
Electrostatic Precipitator				●		●	●			Residues[a]	Residues
Cyclones-Dry				●		●				Residues	Residues
Settling Chambers				●		●					Residues
Baghouse Filters				●		●	●				Residues
Condensers-Boiler Coolers								●		Heat	
Afterburners	●		●		●	●		●	CO2, H_2O Heat		
Adsorbers				●	●	●				Recycled	
Venturi Scrubbers (Wet Cyclone)		●		●		●				H_2SO_3, H_2SO_4 Pathogens	

[a] "Residues" indicates the same or a combined form of the pollutant physically removed.

TABLE 15

EQUATIONS FOR CALCULATING ANNUAL OPERATION AND MAINTENANCE COSTS OF AIR TREATMENT METHODS

	Operation Costs ($)[a]			
Treatment Device	Electrical	Liquor	Fuel	Maintenance Costs ($)
Centrifugal Collector	$\frac{S\,(0.745)PHK}{6356\,E}$	-	-	SM
Wet Collector	S (0.7457)HKZ	SWHL	-	SM
Electrostatic Precipitator	S (JHK)	-	-	SM
Fabric Filter	$\frac{S\,(0.745)\,PHK}{6356\,E}$	-	-	SM
Afterburner	$\frac{S\,(0.7457)\,PHK}{6356\,E}$	-	SHF	SM

[a] The parameters are as follows:

S = Design capacity in cubic feet per minute (cfm).

P = Pressure drop in inches of water.

H = Hours of operation per annum.

K = Cost of electricity in $/KWH (kilowatt hours).

E = Fan efficiency as a decimal.

M = Maintenance costs in dollars (cfm).

F = Fuel costs in dollars/cfm/hour.

W = Make up liquor rate in gallons/hour/cfm.

L = Cost of liquor in dollars/gallon

Z = Total power input required for a specified scrubbing efficiency in horsepower/cfm.

J = Kilowatts of Electricity 1 cfm.

TABLE 16 [258]
CAPITAL COSTS FOR PARTICULATE CONTROL

	Cost ($) for Efficiencies at 100,000 cfm Capacity		
Control	Low	Medium	High
Dry Centrifuge	10,000	18,000	22,000
Wet Collector	13,000	25,000	25,000
High Voltage Electrical Precipitator	47,000	70,000	92,000
Purchase Cost of Fabric Filters	30,000[a]	45,000[b]	85,000[c]
Purchase Cost of Afterburners	115,000[d]		150,000[e]

[a] Woven natural filters.

[b] Medium temperature synthetics - woven and felt.

[c] High temperature synthetics - woven and felt.

[d] 5 x cost of 20,000 cfm direct flame.

[e] 5 x cost of 20,000 cfm catalytic burner.

TABLE 17
ANNUAL CAPITAL AND OPERATING COSTS FOR PARTICULATE CONTROL

	Cost ($) at 100,000 cfm operating 8,000 hours/yr		
Cost Item	Electrostatic Precipitator	High Energy Wet Collector	Medium Temperature Fabric Filter
Purchase Cost $	100,000	27,000	48,000
Installation Costs	70,000[a]	54,000[b]	36,000[c]
Installed Costs	170,000	81,000	84,000
Depreciation (7%)	11,900	5,670	5,880
Capital Charge (7%)	11,900	5,670	5,880
Annual Capital Costs	23,800	11,340	11,760
Maintenance	2,000	4,000	5,000
Electricity	3,520	52,500	7,740
Water	none	6,000	none
Total Operating Costs	5,520	62,500	12,740
Total Annual Costs	29,320	73,840	24,500

[a] Installation cost equals 70% of purchase cost.

[b] Installation cost equals 200% of purchase cost.

[c] Installation cost equals 75% of purchase cost.

Air pollution control costs can be significant in terms of total plant expenditures. A study in the chemical industry found that, for a sample of 992 plants, annual pollution control operating costs were $41,744,000, or $42,080 per plant, and $105.22 per employee. Total capital investment in air pollution control equipment was $287,891,000. On an annual basis, computed at 7 percent interest and 7 percent depreciation, capital costs were $40,304,740 per year, or $40,624 per plant, and $101.54 per employee. The total annual cost, then, was the sum of these or, $82,704 per plant and $206.81 per employee.[259] Another study estimated that the chemical industry controlled 75 percent of its air pollutants.[260] The latter report also concluded that there was a need for a better method to dispose of collected wastes (residues), and that 31 percent of yearly operating costs of air pollution control equipment were for disposal of collected waste.[260] A detailed summary is given in Table 18 .

Wastewater Treatments

Table 19 provides a summary of the various wastewater treatments, the pollutants they affect, and the intermedia transfers created. In many cases, the transfer to land is simply listed as "residue". Unless a biological or chemical reaction takes place, the residue created will be composed of the pollutant removed. For example, screening residue will be composed of the removed organic and inorganic solids. Where gases or other specific compounds are generated they are given in Table 19.

Wastewater Treatment Costs

Water treatment costs vary according to the wastewater and effluent characteristics and size of the treatment facility (economies of scale). Table 20 gives the coefficients for a cost regression equation which were developed in The Economics of Clean Water, a report published by the Environmental Protection Agency.[222] The formula is of the following form:

$$\text{Log (cost)} = A + \text{Log (flow)}\left[(B + C \times \text{Log (flow)}\right]$$

Where: Flow = millions of gallons/day (MGD)

Cost = cost in dollars per year

The table separates capital costs (CC) from operating and maintenance costs (OM). The operating costs determined by the equations are cents/day/1000 gal. Operating costs shown in right hand column are for 350 days per year. Where the constants are negative, they must be changed to negative characteristics and positive mantissas at the final point in the calculation.

Other studies have been made of treatment costs using both flow rates and sludge quantities as the formula parameters.[223] The level of pollutants in the effluents to be treated significantly affects costs and treatment efficiencies. The best choice for any particular application will depend upon many factors, including: (1) size of operation; (2) pollutant concentrations; (3) types of pollutants involved; and (4) the degree of removal required.

TABLE 18[260]
AIR POLLUTION CONTROL EXPENDITURES BY INDUSTRY

	Air Pollution Control Costs			
Source	Waste Disposal ($1/Yr Per Plant)	Operating Cost ($1/Yr Per Plant)	Total Capital Investment & Installation ($)	Waste Disposal Cost As a % of Operating Cost
Food	8,900	36,050	22,020	25
Chemicals	33,200	49,645	89,400	67
Rubber, Plastics	11,950	27,800	149,500	43
Stone, Clay, Glass	7,650	49,820	203,300	16
Primary Metals	7,200	112,150	580,100	7
Fabric Metals	17,200	28,175	36,440	63
Powered Machinery	18,100	67,210	47,000	27
Electrical Machinery	2,520	24,830	202,400	10
Professional and Scientific Instrument	2,750	11,115	41,500	23
Aerospace Manufacturing	13,100	47,400	40,650	28
All Industry Annual Average	14,010	45,450	-	31

TABLE 19
INTERMEDIA TRANSFERS IN WASTEWATER TREATMENT

	WATER POLLUTANTS												INTERMEDIA TRANSFERS		
Treatments	Radioactivity	Organics-Soluble	Inorganic - Soluble	Organics-Insoluble	Inorganic-Insoluble	Sulfur Compounds	Phosphorus Compounds	Nitrogen Compounds	Heavy Metals	Pathogens	Thermal	Acidity/Alkalinity	Air	Water	Land
Screening				●	●										Residues[a]
Flotation	●			●											Residues
Coagulation and Sedimentation	●			●	●		●		●	●					Residues
Chemical Addition	●	●	●	●	●	●	●	●	●			●		Compounds formed	Compounds formed
Trickling Filter		●	●	●	●					●					Residue
Activated Sludge		●	●	●	●	●	●	●		●				Residue sludge	Residue & sludge
Lagoons and Stabilization Ponds		●		●	●	●		●						Residue	Residue
Ion Exchange			●			●	●	●	●			●			Residue
Activated Carbon		●		●		●		●	●					BOD, SS NO_3heavy metals	
Reverse Osmosis			●			●	●	●	●					Residues	Residue
Chlorination										●					
Spray Irrigation		●		●		●	●	●		●					
Ammonia Stripping								●					NH_3	$CaCO_3$	$CaCO_3$
Cooling Towers											●		Heat		
Retention[b]	●													Low-level Radioactivity	Radioactive Drums
Electrodialysis			●			●	●	●	●					Residues	Residues

a. Residues mean the same or a combined chemical term of the pollutant physically removed.

b. Retention by storage as used in nuclear power plants.

TABLE 20

WASTEWATER TREATMENT COSTS

		Model Regression Coefficients			Cost ($) at 1 million gal / day	
Treatment	Type of Cost	A	B	C	Initial Capital	Annual Operating
Oil Separation	CC[a]	4.74702	0.92844	0.22190	55,849	
	OM[b]	0.64345	-0.17671	0.0		15,399
Equalization	CC	4.62325	0.74646	-0.22358	42,000	
	OM	-0.30103	-0.51016	0.06646		1,750
Coagulation-Sedimentation	CC	5.52401	0.61843	0.00842	334,202	
	OM	0.86923	-0.11755	0.00586		25,899
Neutralization	CC	4.69897	0.98569	-0.52716	50,000	
	OM	0.24304	-0.10083	0.0		6,125
Flotation	CC	4.59106	0.44964	-0.02748	38,999	
	OM	0.64345	-0.17671	0.0		15,399
Sedimentation	CC	5.45089	0.55368	0.0	282,416	
	OM	0.64345	-0.17671	0.0		15,399
Aeration	CC	4.54407	0.23408	0.0	35,000	
	OM	-0.30103	-0.51016	0.06646		1,750
Biological Oxidation	CC	5.07555	0.64300	0.0	119,000	
	OM	0.09934	-0.36057	0.07879		4,399
Chlorination	CC	4.17609	0.66317	0.0	14,999	
	OM	0.24304	-0.10083	0.0		6,125
Evaporation	CC	6.11227	1.00000	0.0	1,295,000	
	OM	-0.7112	-0.24314	0.0		2,971
Incineration	CC	5.83373	0.64339	0.0	681,914	
	OM	1.57978	-0.37205	0.0		132,998

a. CC = Capital Cost

b. OM= Operating and Maintenance cost

The Economics of Clean Water report listed four methods of curtailing the polluting effects of industrial liquid-borne wastes.[222]

(1) Inplant treatment
(2) Discharge to sewers
(3) Land application (irrigation or well injection)
(4) Process changes

A detailed cost analysis must be made on an industry-by-industry basis.

Treatment Costs for Thermal Pollution

The annual investment cost, C1, in cents/1000 gal of cooled water may be computed from the equation.

$$C_I = I\ (r + {}^1/t + P)/5.256\ N$$

where, I = cooling tower investment per unit capacity, dollars/gpm

r = annual cost of capital (interest rate) decimal/yr

t = cooling tower service life, yr

P = annual property taxation rate, decimal/yr

Operating costs, C_o, in cents/1000 gal may be computed from

$$C_o = 0.001R\ (C/C-1)\ (C/C-l)(0.033Y + 17/C + Wa) + (0.14K + 0.005A)p$$

where, R = cooling range (temperature change of the water passing through the tower), °F

C = cycles of concentration, dimensionless (i.e.,the ratio of makeup water to the sum of drift loss plus blow down)

Y = alkalinity (as $CaCO_3$) of makeup water, mg/l

Wa = cost of makeup water, cents/1000 gal

K = relative rating factor of the cooling tower, dimensionless

A = height to which the water must be pumped for flow through cooling tower, ft
and

p = cost of electric power, cents/kwh

The figure for Wa is given in terms of water flow rather than power-plant capacity. Table 21 gives the ratio of gpm to kilowatts of capacity. The factor 8/gpm must be multiplied by the appropriate ratio before applying K.

TABLE 21 170

COOLING WATER CIRCULATION (GPM) REQUIRED PER KILOWATT POWER CAPACITY

Overall Effi- ciency (%)	Cooling Range, R (°F)				
	10	15	20	25	30
30	1.37	0.91	0.68	0.55	0.46
35	1.07	0.72	0.53	0.43	0.36
38	0.93	0.62	0.47	0.37	0.31
40	0.85	0.57	0.42	0.34	0.28
42	0.78	0.52	0.39	0.31	0.26

Note: (°F - 32) 0.555 = °C.

GPM = Gallons per minute.

The values of K for both the equations are given in Table 22 . The "approach" is defined as the number of °F that the temperature of the cooling water at the condenser inlet (and cooling tower outlet) exceeds the wet bulb temperature. Therefore, the hot water temperature is the wet bulb temperature plus the approach plus R.

Under typical conditions, the annual investment cost is about $0.003/1,000 gal, and the operating cost is about $0.005/1,000 gal. Therefore, the total cost for the cooling tower is about $0.008/1,000 gal. This figure translates to about 0.3 to 0.4 mill/kwh generated which is 5 to 7 percent of generation costs,or 2 to 3 percent of combined generation and distribution costs.[170]

The Costs of Residue Disposal

Consideration of the method for the disposal of residues from sewage treatment plants and industrial wastes must include both the costs and the environmental effects.

Almost all municipal sewage sludge can be disposed for less than $50 per ton of dry sludge solids.[224] Typical cost ranges for several sludge disposal methods are given in Table 23.

These costs also depend upon the distance to the disposal point. Table 24 illustrates the changing cost relationships between pipelines, tank trucks, and rail cars as distance varies from 25 to 350 miles for a city of 100,000. Also, as distance increases, there is an incentive for methods such as incineration which reduce the mass to be transported. Most sludge disposal sites are within 25 miles of the generation point. Incineration and land disposal exhibit economies of scale. Table 25 indicates the effect of the population served (scale of operations) on residue disposal costs.

Since economies of scale and distance factors interact, a concrete analysis of individual situations is necessary to arrive at an optimal decision. For example, in comparing the costs for liquid sludge land application with the costs of incineration and subsequent ash disposal to landfills, the costs curves for the two methods intersect at 80 miles for a city of 10,000 and a cost of $155 per ton of dry sludge solids; at 45 miles for a city of 100,000 and a cost of $60 per ton; and at 110 miles for a city of 1,000,000 and a cost of $35 per ton.[225]

Residue disposal cost is usually not large relative to total treatment costs. In the case of a recent $120 million plan proposed for metropolitan Seattle, Washington, 90 percent of the costs were for collection and transportation of sewage sludge. Even a choice of the most expensive disposal alternative would not have increased the cost by more than one percent.[224] For smaller scale industrial operations, however, the percentage of costs for residue disposal may not be so low.

The environmental impact of alternative disposal methods is not equal. Many incinerators, for example, do not meet emission standards.

TABLE 22
VALUES OF K FOR FORCED DRAFT COOLING TOWERS

Wet Bulb Temperature (°F)	Cooling Range, R (°F)										
	10			15				20			
	Approach (°F)			Approach (°F)				Approach (°F)			
	5	10	15	5	10	15	20	5	10	15	20
60	2.6	1.4	0.9	—	1.8	1.3	0.8	—	2.2	1.5	1.1
65	2.2	1.1	0.8	3.0	1.6	1.1	0.7	—	1.9	1.3	0.9
70	1.9	1.0	0.7	2.6	1.4	0.9	0.6	3.0	1.6	1.1	0.8
75	1.6	0.8	0.5	2.2	1.2	0.8	0.5	2.5	1.4	0.9	0.7
80	1.4	0.7	0.4	1.8	1.0	0.6	0.4	2.2	1.2	0.8	0.6

Note: (°F - 32) 0.555 = °C.

TABLE 23

RESIDUE DISPOSAL COST RANGES [224]

Disposal Method	Cost Range ($/Ton-Dry Sludge Solids)
Outfall	3-5
Wet Oxidation	30-50
Barge (to sea)	10-20
Pipeline to Land	5-20
Truck to Land	20-50
Rail to Land	30-100
Drying	30-50
Compost	5-10
Incineration	40-50

TABLE 24
RESIDUE DISPOSAL COSTS AS A FUNCTION OF DISTANCE TO DISPOSAL SITE[225]
(DOLLARS/DRY TON SLUDGE SOLIDS)

Transportation Method	Distance to Disposal Site (miles) 25	100	200	350
Pipeline	28	100	180	280
Tank Truck	40	130	220	390
Rail Cars	101	170	180	200

TABLE 25
COSTS OF INCINERATION AND LAND DISPOSAL AS A FUNCTION OF THE POPULATION SERVED[225]

Population (Million)	Cost ($/Ton Dry Sludge Solids)	
	Incineration	Land Disposal
.125	67	30
.250	57	17
.500	49	11
1.0	42	8
2.0	35	5
4.0	30	4

Residues Produced

Five-day biochemical oxygen demand (BOD_5) is one of the parameters used to express wastewater quality. It is a measure of the oxygen required in the biological degradation of the organic materials present in the waste water. It is therefore related in a general way to the suspended solids present in a particular kind of waste. For this reason Table 26 can be constructed to show the relationship between BOD_5 and settleable and suspended solids for the major sources of water pollution in the United States.[109] Table 26 illustrates that it is not possible to project physical residues from BOD removal unless the source is known. The ratio of solids to BOD_5 varies from 9.79 pounds solids per pound of BOD_5 for metal and metal products to 0.20 pounds solids per pound of BOD_5 for chemicals and allied products.

Once both BOD_5 and solids are known, the residues produced from various processes can be estimated. For physical removal methods, residues can be calculated directly from the solids content and the efficiency of removal. Chemical and biological treatment methods create additional residues usually related to the BOD_5 level. Table 27 illustrates these relationships.

Residue Impact

The environmental impact of land disposal takes on added significance with the increasing pressures toward land for the disposal of liquid and solid wastes. Research at Ralph Stone and Company has been conducted regarding the quantity of leachate generated from solid wastes and municipal sewage sludge disposed into landfills.[226] The data given in Table 28 presents total pollutant quantities found in leachates. Monthly data given in Table 29 is the time-averaged BOD_5 depletion (production) rate. The annual production of leachate pollutants can be estimated using average annual rainfall, solid waste and residue disposal data.

TABLE 26[109]

RELATIONSHIPS BETWEEN BOD_5 AND SUSPENDED SOLIDS PRODUCED BY INDUSTRY

SIC Code	Industry	Total Wastewater[a] (Billion gal/yr.)	Settleable and Suspended Solids (Million lb/yr.)	BOD_5 (Million lb/yr.)	Solids/BOD_5 Ratio
33,34	Metal and Metal Products	>4,300	>4,700	>480	9.79
28	Chemical and Allied Products	3,700	1,900	9,700	0.20
c	Power Production	N.A.[b]	N.A.[c]	N.A.	-
26	Paper and Allied Products	1,900	3,000	5,900	0.51
29	Petroleum and Coal	1,300	460	[illegible]	0.92
20	Food and Kindred Products	690	6,600	4,300	1.53
35-37	Machinery and Transportation Equip.	>481	>70	>250	0.28
32	Stone, Clay and Glass Products	(218)[b]	N.A.	N.A.	-
22	Textile Mill Products	140	N.A.	890	-
24,25	Lumber and Wood Products	(126)[b]	N.A.	N.A.	-
30	Rubber and Plastics	160	50	40	1.25
12,19,21, 27,31,38 39,72	Misc. Industrial Sources	450	>930	>390	2.38
	Total Industrial	≧13,100	≧18,000	≧22,000	0.82
	Total Sewers	5,300[d]	8,800[e]	7,300	1.21

[a] Includes cooling water and steam production water

[b] Included in total for all manufacturing

[c] Not available or not applicable (N.A.)

[d] 120 × 10^6 persons × 120 gal/day × 365 days

[e] 120 × 10^6 persons × .2 lbs/day × 365 days

TABLE 27
RELATIONSHIPS BETWEEN RESIDUE QUANTITIES REMOVED BY WASTEWATER TREATMENTS [a]

		Treatment Method							
SIC Code	Industry	Screening	Activated Sludge	Trickling Filter	Lagoons	Chemical Addition	Sedimentation	Flotation	Activated Carbon
02	Feed Lots	S [b]	S+.3B [c]	S+.1B	S+.15B	S+CA [d]	S	S	S+.05B
20	Food and Kindred Products	S	S+.3B	S+.1B	S+.15B	S+CA	S	S	S+.05B
22, 31 61	Wool and Cotton Finishing	S	S+.3B	S+.1B	S+.15B	S+CA	S	S	S+.05B
22, 62	Synthetics Finishing	S	S+.1B	S+.05B	S+.075B	S+CA	S	S	S+.01B
26	Paper and Allied Products	S	S+.15B	S+.07B	S+.1B	S+CA	S	S	S+.02B
2821	Plastics and Resins	S	S+.1B	S+.05B	S+.075B	S+CA	S	S	S+.01B
2873	Nitrogenous Fertilizers	S	S+.3B	S+.1B	S+.15B	S+CA	S	S	S+.05B
2874	Phosphate Fertilizers	S	S+.15B	S+.07B	S+.1B	S+CA	S	S	S+.02B
31	Leather Products	S	S+.3B	S+.1B	S+.15B	S+CA	S	S	S+.05B
35-37	Car and Machine Manufacturing	S	S+.15B	S+.07B	S+.1B	S+CA	S	S	S+.02B
49	Sewage Systems	S	S+.3B	S+.1B	S+.15B	S+CA	S	S	S+.05B
29	Petroleum	S							

TABLE 27 (Cont.)

[a] In all cases these figures represent residues from pollutants removed; that is, if the process for screening in feed lots is 50 percent efficient, the residues will be $.5\ S_o$, where So is the original amount of solids in the effluent.

[b] S = Solids.

[c] B = BOD_5 in lbs.

[d] CA = Chemicals added.

TABLE 28
TOTAL LEACHATE QUANTITIES FROM LANDFILLS[226]

Pollutant	Leachate (Lbs/Dry Ton of Material) Solid Waste[a]	Solid Waste With Sewage Sludge[b]	Solid Waste With Septic Tank Pumpings[c]
BOD_5	15.6	6.6	5.9
Mg	0.294	0.344	0.298
Fe	0.00394	0.00384	0.0039
Zn	0.00738	0.00484	0.00488
Cu	0.0480	0.0362	0.0452
Ba	4.3	4.12	4.28
F	0.0	0.0	0.00
SO_4	0.538	1.062	0.342
PO_4	0.172	0.0121	0.0195
NO_3	0.382	0.00266	0.02
Cl	3.1	4.5	4.54
Ca	2.02	.58	1.39
Total Organic	1.01	1.74	0.766
Total Leachate	11.72	12.41	11.71
Total Inorganic	10.71	10.67	10.94

[a] 54.1 inches of rain, days 0-189, domestic solid waste. BOD_5 figure is for days 0-153.

[b] 54.1 inches of rain, days 0-189, domestic solid waste plus digested sewage sludge (wet) at ratio-1:0.61 lb solid waste/lb wet sludge. BOD_5 for days 0-189 also.

[c] 54.1 inches of rain, days 0-234, domestic solid waste plus septic tank pumpings (wet) at ratio-1:0.61 lb solid waste/lb wet pumpings. BOD_5 is for days 0-198.

TABLE 29
LANDFILL LEACHATE PRODUCTION RATE

	Leachate (Lbs/Ton of Dry Material) [a]		
	Solid Waste	Waste/Sludge	Waste/STP[b]
BOD_5 /Month	3.06	1.05	0.89
Total Leachate/Month	1.81	1.97	1.51
Inorg. Leachate/Month	1.70	1.69	1.41

[a] Columns are identical to corresponding columns on Table 19.

[b] STP = septic tank pumpings.

Intermedia Impacts of Alternative Processes or Treatment Methods

Any production process creates waste material in inverse ratio to its efficiency. Treatment processes for pollution control are also production processes in that they produce a given output from a particular input. Since the wastes produced often vary in kind and amount, the choice of alternative processes often involves trade-offs in both environmental benefit factors and costs. To make optimum selections requires a comparison of negative and positive benefits of both kinds.

Table 30 summarizes the intermedia impacts of alternative industrial processes or pollution control measures for 80 different industries. Residue quantities are listed which affect different media as a function of the residue disposal technique. Because of the lack of space in Table 30, the alternative residue disposal techniques of the air and water treatments are summarized in Tables 30b and 30c.

TABLE 30

POLLUTION CONTROL ALTERNATIVES AND QUANTIFIED INTERMEDIA IMPACTS

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative$^{a, b}$ Residue Quantity (or Impact)	Ref.
01	Agricultural production, Crops,	Eliminate pesticides	Pesticides	Animal and plant disease increase	193
		Biological control	Pesticides	None	193
		Use biodegradable pesticides	Chlorinated hydrocarbons	Lethal damage to humans and animals-short term, high toxicity	193
		Field design	Pesticides in runoff	Pesticides in soil, percolarion to ground waters	193
02	Agricultural production, Livestock-feedlots	Lagoons	BOD,SS in runoff	Nutrients in irrigation water	193
		Detention reservoirs	BOD,SS in runoff	Solids to be dredged.	193
		Paved feedlots	SS, Pathogens in soil	Increase BOD, SS in runoff	193
11,12	Anthracite and bituminous coal mining	Chemical addition (lime-soda ash)	Metallic salts and oxides, pH	Limestone: 30 lb solids/10^3gal. waste	248
142	Crushed stone	Cyclone,fabric filter(ff)	Inorganic particulates	Cyclone: 700-850 lb solids/10^3lb. product; 990 lb residue/10^3lb product as solids.	248
201	Meat products (smoking)	Scrubber and low voltage precipitators	Particulates; aldehydes and organic acids	0.6 lb/lb product as residue water or solids	278
		Afterburner	Hydrocarbons, Carbon Monoxide	Complete combustion products to air, car, steam	278,97

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
201	Meat packing	Lagoons	BOD	120 lb residue/10^3 B.O.D.^{2} dredge as solids	241
202	Cheese production	Trickling filter	BOD	135 lb residue/10^3 lb B.O.D. as solids	239
203	Processed vegetables, potatoes	Sedimentation	BOD,SS	730 lb residue/10^3 lb S.S.	279
203	Canned and frozen fruits and vegetables	Activated sludge	BOD, SS	900–950 lb residue/10^3 lb S.S. as solids	228, 229
				280 lb residue/10^3 lb B.O.D.	230,
		Trickling filter	BOD	45–75 lb residue/10^3 lb B.O.D.	230,237
		Spray irrigation	BOD,SS Nitrogen compounds	Odors	280
208	Breweries	Lagoons	BOD	135 lb residue/10^3 lb B.O.D.	230
		Activated sludge	Phosphorus	957 lb phosphorus/10^3 lb product in waste	234
208	Coffee roasting	Cyclone	Particulates	Quantity depends on process	281,97
22	Textile production, cotton, wool and synthetics	Screening	SS	50–200 lb residue/10^3 lb S.S.	227
		Activated sludge	BOD,SS	850–950 lb residue/10^3 lb S.S. 210–280 lb residue/10^3 lb B.O.D.	227
		Trickling filter	BOD,SS	800–950 lb residue/10^3 lb S.S. 40–95 lb residue/10^3 lb B.O.D.	227
		Lagoons	BOD,SS	300–950 lb residue/10^3 lb S.S. 0–138 lb residue/10^3 lb B.O.D.	227
		Chemical addition	BOD,SS	400–1100 lb residue/10^3 lb S.S.	227
		Sedimentation	BOD,SS	500–650 lb residue/10^3 lb S.S.	111

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
22	Textile finishing wool	Flotation	BOD, SS	500–650 lb residue/10^3lb SS	111
24	Sawmills and board manufacture				
2611	Pulp and paper, pulp mills	Activated sludge	BOD, SS	780 lb residue/10^3lb SS	110
				130–145 lb residue/10^3lb BOD	236
		Lagoons	BOD	80–95 lb residue/10^3lb BOD	244
		Chemical addition ($FeCl_2$ or alum)	SS, phosphorus	500–900 lb residue/10^3 lb SS	249
				1100 lb residue/10^3 lb particulates	
		Electrostatic precipitator	Particulates	940 lb residue/10^3lb particulates	278
		Wet scrubber	Particulates	46 lb residue/10^3 ib particulates	278
243	Fiber-board manufacture	Electrostatic precipitator	Particulates	940 lb residue/10^3lb particulates	96
26	Wall-board manufacture	Baghouse	Particulates		96
		Electrostatic precipitator	Particulates	940 lb residue/10^3lb particulates	96
282	Plastic materials, vinyl polymers	Activated sludge	BOD, SS	980 lb residue/10^3lb SS 90 lb residue/10^3 lb BOD	235
2879	Insecticide manufacture	Baghouse	Particulates	depends on disposal; toxic in water or in runoff from land disposal	96
2899	Fire retardant chemical manufacture	Baghouse	Particulates		96

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
281	Calcium carbide production	Scrubber	Particulates	950-980 lb residue/10^3lb particulates	19
284	Detergent manufacture, drying	Scrubber	Particulates		
281	Sodium phosphate manufacture	Scrubber	Particulates	950 lb residue/10^3lb particulates	45
					45
281	Sodium phosphate manufacture, drying	Cyclone	Particulates	600 lb residue/10^3lb particulates	45
281	Sulfuric acid manufacture	Electrostatic precipitator	Aerosol	Not determined	96
2874	Phosphate fertilizer manufacture	Baghouse	Particulates	Not determined	96
2874	Phosphate fertilizer manufacture (super phosphate)	Scrubber	HF, SiF_4	$\sim$ 195 tons/yr/plant of fluorine from scrubber; 95% removed by slag pile	19
2874	Phosphoric acid manufacture	Scrubber	H_3PO_4 aerosol	$>$ 999 lb residue/10^3 lb acid	264
2874	Phosphoric acid manufacture	Scrubber	Particulates	$>$ 980 lb residue/10^3 lb acid	278
2874	Thermal process	Mist eliminator	Particulates	990-999 + lb residue/10^3lb acid	278
		Electrostatic precipitator	Particulates		278
2895	Carbon black manufacture, furnace process	Cyclone	Particulates	Not defined–depends on disposal method	278

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
2895	Carbon black manufacture, furnace process	Cyclone and scrubber	Particulates	Not defined-depends on disposal method	278
		Fabric filter	Particulates	Not defined-depends on disposal method	278
		Thermal process	Particulates, Hydrocarbons	None	278
291	Petroleum refineries, fluid bed catalytic cracking unit	Moving bed catalytic converter unit	SO_x, CO, NO_x particulates, hydrocarbons	None	
291	Petroleum refineries, crude oil Distillation unit	Vapor control system	Hydrocarbons (gaseous)	None	96
291	Petroleum refineries, fluid bed	CO boiler	CO	None	96
291	Petroleum refineries	Cyclone	Particulates	700 lb residue/10^3lb particulates	45,96
		Flare (and vapor manifold)	Hydrocarbons (gaseous)	Complete combustion products	96
		Electrostatic precipitation	Particulates	850 lb residue/10^3lb particulates	45,96
295	Asphalt manufacture, blowing	After burner	Hydrocarbons	None - complete combustion products	96
245	Asphalt manufacture, rotary dryer	Pre-cleaner, high efficiency cyclone	Particulates	Land or air pollutants, depending upon disposal methods	278
		multiple centrifugal,	Particulates	Same	278
		scrubber	Particulates	Water borne wastes, equal to weight of particulates	278
		Baffle spray tower	Particulates	same	278

TABLE 39 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
31	Leather tanning and finishing	Activated sludge	BOD, SS Chromium Compounds, sulfur compounds	~800-950 lb residue/10^3 lb SS ~255-285 lb residue/10^3 lb BOD	73
		Trickling filter		850-900 lb residue/10^3 lb SS 65-80 lb residue/10^3 lb BOD	73
		Chemical addition		750 1000 lb residue/10^3 lb SS	73
		Sedimentation		700-960 lb residue/10^3 lb SS	235
		Lagoons	BOD, SS chromium compounds	800 lb residue/10^3 lb SS 100 lb residue/10^3 lb BOD	73
324	Cement manufacture, dry process	Wet process	Particulates	None: recovered	282, 278
325	Ceramic clay manufacture	Cyclone	Particulates	700 lb residue/10^3 lb particulates	278
327	Concrete manufacture, Brick manufacture	Scrubber	Particulates	950 lb residue/10^3 lb particulates	282
		Baghouse	Particulates		96
329	Asphalt tile manufacture	Baghouse	Particulates		96
327	Lime production	Baghouse	Particulates	990+ lb residue/10^3 lb particulates	261
		Scrubber	Particulates	960-995 lb residue/10^3 lb particulates	261
		Cyclone	Particulates	600-700 lb residue/10^3 lb particulates	261
		Electrostatic precipitator	Particulates	950 lb residue/10^3 lb particulates	261

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
331	Coke production	Scrubber	Particulates		96
	Iron and steel production	Chemical addition	Fe wastes	1050 lb residue/10^3lb Fe	247
		Limestone and aeration			
		Baghouse	Particulates	920 lb residue/10^3lb particulates	45
	Iron and steel production, blast furnace	Water spray	Particulates		15
	Iron and steel production, open hearth furnace	Electrostatic precipitator	Particulates	920 lb residue/10^3lb particulates	45,96
		Scrubber	Particulates and organic gases	200 lb residue/10^3lb gases	45
	Iron and steel production, basic oxygen furnace	Electric arc furnace	Particulates and organic gases	None to negligible	278
	Iron and steel production, electric arc furnace	Baghouse	Particulates and organic gases	Not determined.	
		Sedimentation	SS	910–940 lb residue/10^3lb SS	251
332	Gray iron foundry	Electrostatic precipitator	Particulates	920 lb residue/10^3lb particulates	45
		Baghouse	Particulates	920 lb residue/10^3lb particulates	45
		Scrubber	Particulates	300–650 lb residue/10^3lb particulates	45
		Afterburner	Organic and inorganic gases	Complete combustion products	
332	Gray iron foundry, cupola, furnace	Reverberatory furnace	Particulates, carbon monoxide	None	278
		electric induction furnace	particulates, carbon monoxide	None	278

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
332	Steel foundaries, electric arc furnace	Electric induction	Particulates, NO_x	None	278
		furnace, open hearth	Particulates, NO_x	None	278
		furnace, open hearth-oxygen lance			
333	Zinc production	Baghouse	Particulates		96
333	Zinc smelting	Retort reduction furnace	Particulates	None	278
		horizontal muffle fur-	Particulates	None	278
		nace, pot furnace,	Particulates	None	278
		sweat furnace	Particulates	None	278
333	Lead smelting	NaOH scrubber	SO_x	1300 lb residue/10^3lb SO_x (as SO_3)	278
		Water spray	SO_x	520 lb residue/10^3lb SO_x (as SO_2)	278
333	Lead smelting, cupola furnace	Pot furnace	Particulates, SO_x	None	278
		Reverberatory furnace	Particulates, SO_x	None	278
		Rotary reverberatory furnace	Particulates, SO_x	None	278
333	Primary aluminum production	After burner	Particulates	Complete combustion products-air	96
333	Copper smelting	Baghouse	Particulates	Land or water residues=920 lb particulates, depending on disposal method	278
		NaOH scrubber	Particulates, SO_x Particulates	Water residue: 500 lbs/10^3 lbs. Particulates treated plus 2.22 $_x SO_2$ removed + 1.775 x SO_3 removed	

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
333	Copper smelting	Water scrubber	Particulates	Water residue: 500 lb/10^3lb particulates	278
334	Secondary aluminum production	Baghouse	Particulates	700 lb residue/10^3lb particulates	278
		Electrostatic precipitator	Particulates	700 lb residue/10^3lb particulates	278
		Crucible furnace	Particulates	None	
		Reverberatory furnace	Particulates	None	
336	Yellow brass production	Baghouse	Particulates		96
34	Electroplating	Activated carbon	Aqueous chromium compounds	~950 lb residue (as Cr)/10^3lb Cr	216
		Reverse osmosis	Chromium, nickel compounds	987–998 lb residue (as Ni, Cr)/lb metal	255, 256
36	Electrical equipment manufacture				
37	Automobile manufacture	Activated sludge	BOD, SS	850–950 lb residue/10^3lb SS 120–140 lb residue/10^3lb BOD	233
40	Railroad transportation				
41	Automotive transportation	California (1966) "smog control" device	CO, hydrocarbons	Complete combustion products	283, 278
42	Truck transportation				

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
45	Air transportation, turbine, turbine "A" fuel	Additive of ethyl corp. "CI-2" to fuel	Particulates	Complete combustion products	266
		Use of JP-4 fuel	Particulates, SO_x, hydrocarbons and organic gases	Same	266
		Use of "smokeless" burner cans	Particulates, CO, hydrocarbons, organic gases	Same	266
4911	Electric power generator, coal, pulverized firing	Filter (siliconized glass)	Particulates	20×10^6 tons fly ash (U.S.) in 1965; 3% marketed	19
	Electric power generator coal, high-rate on-grate firing and spreader stoker	Cyclone	Particulates	30×10^6 tons fly ash (U.S.) in 1970; 2.5% utilized at all (ref. 298); 1/3 could be used as sludge conditioner	19
	Electric power generator, coal, small plant	Inertial collector	Particulates	Not determined	19
	Electric power generator, coal, underfeed, vibrator, chain and traveling grate	Gravity settling	Particulates	300-750 lb residue/10^3lb particulates	19
	Electric power generator, coal, pulverized firing	Electrostatic precipitator	Particulates	850-990 lb residue/10^3lb particulates	
	Electric power generator, coal, pulverized firing, spreader stoker	Scrubber	Particulates, SO_2 NO_2	750 lb residue/10^3lb particulates 1050 lb residue/10^3lb SO_x (as SO_3) (soda-ash scrubber)	19, 12, 265
	Electric power generator, coal	Limestone injection into furnace two-stage combustion, low excess air	SO_2 NO_x	 Sulfate residue	12 44

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or impact)	Ref.
4911	Electric power generator, coal, pulverized firing	Cyclone firing	Particles	None	44
4952	Municipal sewage systems	Activated sludge	BOD	120 mgd sludge (U.S.) in 1970 270 lb residue/10^3lb BOD	84
		Chemical addition	Phosphorous compounds	1100 lb residue/10^3lb phosphorous (with $Fe\ Cl_2$)	84
		Activated carbon	BOD, phosphorous compounds		84
		Ion exchange	Nitrogen compounds	930-970 lb residue/10^3lb nitrogen	35
4953	Municipal refuse incineration, single chamber	Settling chamber	Particulates	Retained in ash	284
		Wetted baffle	Particulates	620 lbs water residue/10^3lb particulates	284, 285
		"Wet collection"	Particulates	Same	286
		Electrostatic precipitator	Particulates	Retained in ash	286
		Settling chamber and spray system	Particulates	500 lbs water residue/10^3lb particulates	278
		Multiple chamber incinerator	Particulates, NO_x Hydrocarbons	Complete combustion products	278
		Scrubber	Polynuclear hydrocarbons	N.D. or uncontrolled	287
		Spray system	NO_x	N.D. or uncontrolled	288
5541	Gasoline service stations				

TABLE 30 (cont.)

SIC Code	Industry and/or Source	Alternative Process or Treatment Method	Pollutant Removed	Direct Intermedia Impact of Alternative Residue Quantity (or Impact)	Ref.
72	Dry cleaning	Activated carbon	Hydrocarbons	If regenerate-recover solvent if not regenerated - contaminated sludge to water - 960 lbs/10^3 lbs hydrocarbons plus activated carbon used in process (about 3.33 lbs/lb hydrocarbons removed)	332 333

---

[a] Unless otherwise stated, figures given as pounds of residue per pound of pollutant are per pound of pollutant treated, not per pound of pollutant removed.

[b] Intermedia impacts reflect the increase in another pollutant form or media of the alternative. Therefore, where an alternative simply reduces pollutant discharges with no intermedia or form transfer, the intermedia impact is given as "none". This does not mean that all pollution has been eliminated for this process. For various process and treatment coefficients please see Tables 31 and 32 and Appendix.

Intermedia Residue Disposal Techniques

Tables 30 (b) and 30 (c) describe the major direct intermedia transfers resulting from alternative residue disposal techniques for air and water pollutants. The Tables indicate the residue disposal techniques for various treatment methods and whether these techniques affect the air, water or land. Although transfers between air and water are not as common as from air to land or from water to land, there are several important and significant air-water transfers.

Residue Disposal Techniques for Air Pollutant Residues

Table 30 (b) lists the alternative residue disposal techniques for air pollutant residues. Most air treatment techniques are either intramedial processes, or create air to land transfers. The Regional Case Study (see Section IX) indicated that these air to land and intramedial techniques are gaining in use over techniques that create air to water transfers. Several types of air-to-water transfers do, however, remain as major factors to be considered. Water scrubbers create waterborne residues. Table 30 (b) also indicates that it may be possible to use lime slurry treatments to extract compounds of calcium (calcium fluoride, calcium sulfate, etc.) from scrubbing water to prevent the transfer from air to water and dispose the residues to the land. In addition, dry collection devices sometimes are flushed with water in order to remove the collected residues. The above practice seems, however, to be declining. Activated carbon devices are currently being used to control hydrocarbon emissions from organic solvent uses, for example, in dry cleaning establishments. For economic reasons, the carbon is usually regenerated with steam for reuse. This creates a transfer to water of the hydrocarbons in the condensing steam.

Residue Disposal Techniques for Water Pollutant Residues

Table 30 (c) lists the alternative residue disposal techniques in water pollutants. Although the trend is toward land disposal several significant water-to-air transfers do exist. Recently concern has been expressed because of the disposal of hazardous wastes at landfill sites.[325] Because of the potential danges of landfill leachate contamination or dangers of direct human contact or volatility of these wastes, their disposal by landfillins is being restricted and carefully controlled.[325] The result is that there has been an increase in the storage of these hazardous wastes at industrial sites.[325,326] The most significant water-to-air transfer results from the incineration of sewage sludge which is widely practiced throughout the nation. The alternatives to incineration include ocean dumping, landfilling, land spreading, or agricultural application. Ocean dumping is now prohibited,and communities practicing this must find other disposal means. Since nearly all wastewaters in Los Angeles City are discharged to the sewer system, this provides a reliable basis for estimating the impact of changing to the landfilling of sewage sludges. Data calculated in the Regional Case Study indicate that only about a two percent increase in landfill solids would result from the disposal of sewage sludge in landfills.(See Section IX for more detailed discussion.) Nearly 10,000 tons per day of solid refuse are collected in the City,[322] while only 200 tons per day of solids would

TABLE 30 (b)
AIR TREATMENT RESIDUE DISPOSAL TECHNIQUES

Treatment	Residue Media	Residue Disposal Method
Cyclones	Land	Dry removal and disposal to landfill
	Water	Flush with water
	Air	Incineration of wastes
Activated Carbon	Land	No regeneration-disposal of saturated carbon
	Water, land	Periodic disposal of spent carbon Some contaminated sludge from regeneration goes to water
Flares	Air	No residue collection - completes combustion process
Filters	Land	Dry removal of residues - vibration unusual but residues vibrated into a hopper
	Water	May be flushed with water
	Air	Incineration of wastes
Electrostatic Precipitator	Land	Dry removal of residues to landfill
	Air	Incineration of wastes
Gravity Settling Chamber	Land	Dry removal
	Water	Flush residues with water
	Air	Incineration of wastes
Scrubbers	Water	Process water to sewer or stream
	Land	Lime slurry treatment - removes calcium fluoride, calcium sulfate, etc., on settling ponds
Water Spray	Water	A type of scrubber - water directly to water body
	Land	Lime slurry treatment for removal of calcium fluoride, calcium sulfate, etc., on settling ponds
Afterburner	Air	No removal - complete combustion products
Furnace Limestone Injection	Land	Sulfate residues removed as slag
Fuel Additives	Air	Facilitate complete combustion
Vapor Control Systems	None	Retention of vapors in original solution
Burner Cans for Planes	Air	Complete combustion process

TABLE 30 (c)
WATER TREATMENT RESIDUE DISPOSAL TECHNIQUES

Treatment	Residue Media	Residue Disposal Method
Screening	Land	Disposal to landfills
	Air	Incineration
Activated Sludge	Land	Landfills, or agricultural application
	Water	Pumping to ocean or other water body
	Air	Sludge incineration
Trickling Filter	Air	NH_3, NO_2, NO_3 liberated by bacterial and enzyme action
	Land	Disposal to landfill of settled material
	Water	Pumping of settled slurry to sea or other water bodies
	Air	Incineration of settled material
Lagoons and Stabilization Ponds	Air	Escape of gases from decomposition process
	Water	Non-decomposed overflow from lagoons
	Land	Periodic dredging of settled inorganics
Chemical Addition	Land	Sedimentation of coagulated material
Stripping Towers	Air	Release of NH_3 by alteration of surface tension
Sedimentation	Land	Disposal to landfill or agricultural application
	Air	Incineration of residues
Flotation	Land	Disposal to landfill or agricultural application
	Air	Incineration of residues
Electrodialysis	Land	Evaporation of slurry - landfill disposal
	Water	Flushing of membrane with water. Process water cleaned and slurry to sewer or water body.
Activated Carbon	Land	Disposal of saturated carbon
	Water	Carbon regeneration with steam
Ion Exchange	Land	Evaporation and disposal of slurry
	Water	Regeneration of resin. Recovery of nitrogen and other adsorbed material from regenerent salt solution (negligible).

TABLE 30 (c) (Cont.)

Treatment	Residue Media	Residue Disposal Method
Reverse Osmosis	Land	Evaporation and landfill disposal
	Water	Flushing membrane with water - slurry to ocean or water body
Spray Irrigation	Land	A residue disposal technique - waste application to agricultural land.
Chlorination	None	Use for disinfection of wastewater
	Air	Ammonia, nitrogen wastes converted to nitrous oxide-released to atmosphere Oxidation and breakdown of organic material
Prevention of Dumping of Hazardous Wastes	Land	Landfill disposal of hazardous chemicals
Sewage Sludge Drying or Digestion	Land	Landfill disposal of dry/digested material
	Air	Gases given off by drying or digestion process

be generated by secondary treatment at the City's Hyperion Treatment Plant.[306]

Other water-to-air transfers exist and are more difficult to control. Trickling filters, stripping towers, lagoons, aeration, and chlorination result in the release of various gases to the air as a result of the chemical, bacterial and enzymatic actions. These transfers have not, however, made major impact on ambient air quality.

Table 31 describes, in full, disposal techniques for air pollutants. Table 32 describes, in full, disposal techniques for water pollutants.

TABLE 31

AIR TREATMENT LIST

MEDIUM: AIR

CONTROL METHOD: CYCLONE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Coffee roasting, stone and cooler	20	Particulates		70				97
Lime production, pulverized limestone dryer	32	Particulates	@2.4 gr/ft^3	60-70				261
Lime production, rotary kiln	32	Particulates	@4.3 gr/ft^3	70			High efficiency cyclones	261
		Particulates	@5 gr/ft^3, 60,000 cfm	65.3	$9,200, or $0.14/cfm	$4,900/yr tot:0.02¢/10^3 ft^3	Simple cyclone	57
		Particulates	@5 gr/ft^3, 60,000 cfm	84.2	$17,600, or $0.28/cfm	$6,500/yr tot:0.029¢/10^{3}ft^3	High efficiency cyclone	5
		Particulates	@5 gr/ft^3, 60,000 cfm	91.0	$21,800 or $0.36/cfm	$7,900/yr tot:0.034¢/10^{3}ft^3	Irrigated cyclone	5
		Particulates	@5 gr/ft^3, 60,000 cfm	93.8	$19,300 or $0.31/cfm	$5,700/yr tot:0.027¢/10^{3}ft^3	Multicyclone	5
Sodium phosphate mfg., drying	28	Particulates	@160 lb/hr (0-5)	60 (0-5)	$20,000 for 50 KT/yr plant	$2,000/yr	Primary cyclone	45
		Particulates	@100 lb/hr (0-5)	75 (0-5)	$40,000 for 50 KT/yr plant	$4,000/yr	Secondary multi-tube cyclones	45

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: CYCLONE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Petroleum refineries, cat. cracking	29	Particulates	@100 lb/hr (0-5μ)	70 (0-5μ)	$240,000 for 42 K bbl/day unit	$15,000/yr		45
Elec. power prod. on-grate, high rate firing; some spreader st.	49	Particulates		50-90 (>20μ)		$125-250/ 10^3 cfm	Single cyclone, large diameter	19
Electric power prod. coal, spreader stoker	49	Particulates		75-90 (>10μ)		$150-300/ 10^3 cfm	Multicyclone, small diameter tubes possible abrasion prob.	19
Petroleum refineries, fluid c.c. unit	29	Particulates			$165,000 for 40 K bbl/day unit		L.A. County	96
Chemical drying, detergents	28	Particulates	@3 gr/ft^3	90(by gr count)				15
Electric power gen.; coal; spreader, chain grate, vibrator stokers	49	Particulates		60			Large diameter	16
Electric power gen., coal, spreader, chain grate, vibrator stokers	49	Particulates		60			Large diameter	16
Electric power gen., coal, spreader, chain grate, vibrator stokers	49	Particulates		85			Small diameter	16

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: CYCLONE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Electric power gen., coal, spreader, chain grate, other stokers	49	Particulates		65			Large diameter	16
Electric power gen., coal, spreader, chain grate, other stokers	49	Particulates		90			Small diameter	
Electric power gen., coal, spreader, chain grate, cyclone firing	49	Particulates		15			Large diameter	16
Electric power gen., coal, spreader, chain grate, cyclone firing	49	Particulates		70			Small diameter	16
Electric power gen., coal, spreader, chain grate, other pulverized units	49	Particulates		30			Large diameter	16
Electric power gen., coal, spreader, chain grate, other pulverized units	49	Particulates		80			Small diameter	16
Petroleum refinery, FCC	29	Particulates	2800 gr/ft^3, 37.0 medium 40,000 ft^3/min	99.98			Series cyclone high pressure drop	16

TABLE 31 (cont.)
CONTROL METHOD: CYCLONE

MEDIUM: AIR

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Abrasive cleaning	34	Particulates (talc)	2.2 gr/ft^3, 2,300 ft^3/ min.	93			0.33 in pressure drop	16
Drying, sand and gravel	32	Particulates	38.0 gr/ft^3, 8.2 median, 12,300 ft^3/min.	86.9			1.9 in pressure drop	16
Grinding, aluminum	33	Particulates	0.7 gr/ft^3, 2,400 ft^3/min.				1.2 in pressure drop	16
Planing mill, wood	24	Particulates	0.1 gr/ft^3, 3,100 ft^3/min.	97			3.7 in pressure drop	16
Grinding, iron scale	33	Particulates	0.15 gr/ft^3, 3.2 median 11,800 ft^3/min.	56.3			Impeller collector, 4.7 in pressure drop	16
Rubber dusting (zinc stearate)	28	Particulates	0.6 gr/ft^3, 0.7 median, 3,300 ft^3/min.	88			Impeller collector, 0.9 in pressure drop	16

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: CYCLONE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
		Particulates	@10 @20 @>40	80 94 97			High-draft-loss collector, 2.5 in. H_2O; spe. grav. fly ash: 2.0	262
		Particulates	@20 @40 @80	35 74 95			Medium-draft-loss collector, 0.4 in. H_2O; sp. grav. fly ash: 2.0	262
		Particulates	@40 @80 @160	50 78 93			Low-draft-loss collector, 0.2 in. H_2O; sp. grav. fly ash: 2.0	262
Electric power prod. coal, small plant	49	Particulates	@725	65	\$100-200 /10^3 cfm		Medium-draft-loss (0.4-1.5 in. H_2O): for very critical on-grate firing	19

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: ADSORBER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Rotogravure press	27		(See under "cap. cost")		$40,000 for 5-color, 44-in. web plant		Activated carbon; L.A. County	96
Dry cleaner, synth. solvent	72		(See under "cap. cost")		$3,000 for 60 lb/batch unit		Activated carbon; L.A. County	96

TABLE 31 (cont.)

MEDIUM: AIR   CONTROL METHOD: FLARES

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Liquid hydrogen mfr.	28		(See under "cap. cost")		$17,700 for 32T/yr plant			96
Natural gas prod.	13	Org. gases	(See under "cap. cost")		$5,000 for 20M ft^3/day plant		(Includes vapor manifold)	96
Synth. rubber mfr.	28	Org. gases	(See under "cap. cost")		$250,000 for 30 KT/yr plant		(Includes vapor manifold)	96
Petroleum refinery, fluid C.C. unit	29	Org. gases	(See under "cap. cost")		$363,000 for 40 K bbl/day plant		(Includes blowdown systems and vapor manifold)	96

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: FILTERS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
		Particulates			$220-8400/ 1000 cfm *		Woven fabric or felt, tubular(30,000 -1000 cfm)	
		Particulates			$460-$720/ 1000 cfm *		panel (30,000-5000 cfm)	
		Particulates			$650-$950/ 1000 cfm *		, reverse jet (felt) (20,000-5000 cfm)	
		Particulates			$7/1000 cfm *		Fiber (throwaway, (any flow rate)	
		Particulates			$15/1000 cfm *		Knitted metal (viseous) (any flow rate)	
Asphalt tile prod.	32	Particulates	(See under 'unit cost")		$5,000 for 5,000 lb/hr plant		L.A. County	96
Concrete batching	32	Particulates	(See under "unit cost")		$10,000 for 900,000 lb/hr unit		L.A. County	96
Yellow brass prod. crucible furnace	33	Particulates	(See under "unit cost")		$17,000 for 4 furn. of 850 lb charge/heat		L.A. County	96
Steel prod., electric arc furnace	33	Particulates	(See under "unit cost")		$45,000 for 18T/heat furnace		L.A. County	96

* Cost based on air-cloth ratio of 2 cfm/ft^2

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: FILTERS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Brass prod. electric induction furnace	33	Particulates	(See under "unit cost")		$2,700 for 2000 lb/hr furnace		L.A. County	96
Enamel frit drying	75	Particulates	(See under "unit cost")		$3,000 for 1,500 lb/hr unit		L.A. County	96
Fire-retardant mfg.	28	Particulates	(See under "unit cost")		$2000 for 1000 lb/hr unit		L.A. County	96
Zinc prod. galvanizing kettle	33	Particulates	(See under "unit cost")		$3000 for 4' x30' x 4' unit		L.A. County	96
Grit blasting machine	34	Particulates	(See under "unit cost")		$1,700 for 6 ft^3 unit		L.A. County	96
Insecticide mfg.	28	Particulates	(See under "unit cost")		$3,000 for 1000 lb/hr unit		L.A. County	96
Lime prod. calcinatic kiln	32	Particulates		99.2			Glass bag filter	261
Lime prod. - conveying, hydrate milling	32	Particulates		99+			Cloth bag	261
		Particulates		99.9	$47,600, or $0.78/cfm	$18,700/yr.	Reverse jet-fabric filter (1967)	5
		Particulates		99.9	$49,300 or $0.81/cfm	$14,200/yr.	Conventional fabric filter (1967)	5
Gray iron foundry	33	Particulates	(See under "unit cost")	92 (0-54)	$50,000 for 4000 T/yr plant	$5,000/yr.		45

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: FILTERS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Steel prod.	33	Particulates	(See under "unit cost")	92 (0-5μ)	$425,000 for $25M plant-4 open hearths	$40,000/ yr.		45
Sodium phosphate (drying)	28	Particulates	(See under "unit cost")	99 (0-5μ)	$90,000 for 50 KT/yr plant	$9,500/yr		45
Electric power gen., coal-fired	49	Particulates		98-99 (<1-44μ)	$\frac{\text{Total costs:}}{1000 \text{ cfm}}$	$600-1000/	Rec. for pulverized firing; exit T limit: 600°F; siliconized glass filter	19
Phosphaic fertilizer prod.	28	Particulates	(See under "unit cost")		$5,000 for 2000 lb/hr unit		L.A. County	96
Rubber Banbury mixer	28	Particulates	(See under "unit cost")		$3,000 for 1000 lb/hr unit		L.A. County	96
Sandblast room	34	Particulates	(See under "unit cost")		$3,000 for 8' x 12' x 8' min.		L.A. County	96
Sewer pipe mfg.	32	Particulates	(See under "unit cost")		$10,000 for 20 klb/hr plant		L.A. County	96
Ship bulk loading	44	Particulates	(See under "unit cost")		$168,000 for 2.5 KT/hr operation		L.A. County	96
Wallboard prod.	26	Particulates	(See under "unit cost")		$100,000 for 60 Klb/hr plant		L.A. County	96

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: FILTERS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Electric power gen., coal, spreader, chain grate, vibr. stokers	49	Particulates		99.5			"Under development"in 1968	16
Electric power gen., coal; spreader, chain grate, cyclone firing	49			99.5			"Under development" in 1968	16
Electric power gen., coal, spreader, chain grate, other pulver. units	49	Particulates		99.5			"Under development" in 1968	16

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: ELECTROSTATIC PRECIPITATOR

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Lime prod. rotary kiln	32	Particulates		95.0			Single stage	261
		Particulates		94.1	$86,000, or $1.43/cfm	$2,400/yr Tot. 0.038¢/$ft^3$	for 5 gr/ft^3	5
		Particulates		99.0	$148,000, or $2.46/cfm	$5,488/yr Tot. 0.070¢/$ft^3$	for 5 gr/ft^3	5
Gray iron foundry	33	Particulates	(See under "unit cost")	92 (0–5 μ)	$75,000 for 8T/hr plant (4000T/yr)	$6,500/yr		45
Steel prod., open hearth furnace	33	Particulates	(See under "unit cost")	92 (0–5 μ)	$800,000 for 4 open hearths	$50,000/yr		45

TABLE 31 (cont.)
CONTROL METHOD: ELECTROSTATIC PRECIPITATOR

MEDIUM: AIR

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Petroleum refineries	29	Particulates	(See under "unit cost")	85 (0-5μ)	$1.1M for 42 K bbl/day operation	$20,000/yr.	removal eff.: 0% overall partic. eff.: 98%	45
Petroleum refineries	29	Particulates	(See under "unit cost")	85 (0-5μ)	$1.5M for 42 K bbl/day operation	$20,000/yr.	Gas removal eff. 0%; replacement pptr.	45
Electric power gen., coal-fired (pulverized)	49	Particulates	(See under "unit cost")	85-99 (1-10μ)	$300-$1000/10^3 cfm			19
Fiberboard prod.		Particulates	(See under "unit cost")		$15,000 for 16T/hr oper.		L.A. County	96
Petroleum refineries, fluid C.C. unit	29	Particulates	(See under "unit cost")		$1.04M for 40 K bbl/day unit		L.A. County	96
Steel prod. open hearth	33	Particulates			$150,000 for 60T/heat furn.		L.A. County	96
Sulfuric acid prod.	28	Particulates	(See under "unit cost")		$150,000 for 250T/day plant		L.A. County	96
Incinerator, munic.	49	Particulates	(See under "unit cost")		$2,409,200 for 800T/day oper.	$512,500/yr.		263
Electric power gen., all firing, stoking methods (coal)	29			99.5				16
Electric power gen., oil-fired	29	Particulates		75.0				16

TABLE 31 (cont.)

MEDIUM: AIR CONTROL METHOD: GRAVITY SETTLING CHAMBER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Electric power prod., coal	49	Particulates	45 45	30-40 /10^3 cfm	$100-200		For underfeed, vibrating, chain and traveling grate stokers.	19
Electric power prod., coal spreader, chain grate, and vibrator stokers	49	Particulates		50			"In operation" in 1968	16
Electric power prod., spreader, chain grate, and other stokers	49	Particulates		60			"In operation" in 1968	16
Electric power prod., coal, spreader, chain grate, cyclone firing.	49	Particulates		10			"In operation" in 1968	16
Electric power prod., spreader, chain grate, other pulverized units	49	Particulates		20			"In operation" in 1968	16
Electric power prod., coal, spreader, chain grate, oil-fired	49	Particulates		5			"In operation"in 1968	16

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: SCRUBBER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Gray iron foundry	33	Particulates	(See under "unit cost")	65 (~ 4% > 5 μ)	$30,000	$4,500/yr	Est'd, 1959	45
Steel prod., open hearth furnace	33	Particulates	(See under "unit cost")	40 (0-5 μ)	$200,000 for 4 furnaces	$30,000		45
Steel prod., open hearth furnace	33	Organics and gases	(See under "unit cost")	20	$200,000 for 4 furnaces	$30,000		45
Electric power prod., coal, spreader stoker, pulverized firing	49	Particulates		75 (>2 μ)	Total $200 / cfm	1000/1000	Possible problems of caking and corrosion	19
Asphalt batching	29	Particulates	(See under "unit cost")		$10,000 for 100 T/hr plant		L. A. County	96
Ceramic tile prod.	32	Particulates	(See under "unit cost")		$10,000 for 4 T/hr oper.		L.A. County	96
Chrome plating	34	Particulates	(See under "unit cost")		$800 for 4' x 5' x 5' chamber		L.A. County	96
Coke prod., delayed coker unit	33	Particulates	(See under "unit cost")		$385,000 for 27,900 bbl/day plant		L.A. County	96
Pipe coating, incl. spinning, wrapping, dipping	32	Particulates	(See under "unit cost")		$32,000 for 4-10 lengths/hr		L.A. County	96
Rock crushing and sizing	32	Particulates	(See under "unit cost")		$2,000 for 150T/hr operation		L.A. County	96

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: SCRUBBER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Phosphoric Acid Mfg.	28	H_3PO_4 aerosol		99.9+			"High eff. mist collector, new"	264
Starch mfr.	20	Particulates		98			Centrifugal gas scrubber	97
Lime mfr., rotary kiln	32	Particulates	@ 0.02 - 0.08 gr/ft^3	97.5 99.7			4-stage cyclonic scrubber	261
Lime mfr., rotary kiln	32	Particulates	@ 0.12-0.25 gr/ft^3	96-97			Venturi scrubber	261
Lime mfr., rotary kiln	32	Particulates	@ 0.3 -0.4 gr/ft^3	97.5			Impingement scrubber	261
Typical performance		Particulates	@ 5 gr/ft^3	97.9	\$28,800, or \$0.48/cfm	\$10,500 Totl.:0.047¢/10^3 ft^3	Impingement scrubber	5
Typical performance		Particulates	@ 5 gr/ft^3	99.7	\$42,000, or \$0.70/cfm	\$33,800 Tot.: 0.128¢/10^3 ft^3	Venturi scrubber	5
Typical performance		Particulates	@ 5 gr/ft^3	98.5	\$66,600, or \$1.12/cfm	\$66,500 Tot:0.257¢/10^3 ft^3	Disintegrator scrubber	5
Gray iron foundry	33	Particulates	(See under "unit cost")	30 (37% $>5\mu$)	\$30,000 for 8T/hr plant	\$4,500/yr		45

TABLE 31 (cont.)

MEDIUM: AIR CONTROL METHOD: SCRUBBER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Fertilizer prod., superphosphate	28	HF, SiF_4		93			Jet-venturi fume scrubber	15
Calcium carbide prod.	28	Particulates		95-98			Pease-Anthony scrubber	15
Chemical drying	28	Particulates	@0.3 gr/ft^3	70 (by gr count)			Venturi scrubber	15
Sodium phosphate mfr., drying	28	Particulates	@ 8 lb/hr (0-5μ)	95 (0-5)	$70,000 for 50 KT/yr plant	$8,000	Secondary scrubber	45
Electric power prod., coal	49	SO_2		75	$5.00/KW	$2.50/ T coal	Soda ash solution	12
Incinerator, munic.	49	Particulates	(See under "cap. cost")		$1,838,600 for 800T/day oper.	$401,000/ yr		264
Electric power gen., coal	49	NO_2		15-30			By-product of SO_x scrubbing (using alk. scrub)	263
Electric power gen., coal, spreader, chain grate, vibrating stokers	49	Particulates		99+			8-in. (H_2O) pressure-drop scrubbers	16
Electric power gen., coal, spreader, chain grate, cyclone firing	49	Particulates		99+			8-in. (H_2O) pressure-drop scrubbers	16
Electric power gen., coal, spreader, chain grate, cyclone firing	49	Particulates		99+			8-in (H_2O) pressure-drop scrubbers	16

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: WATER SPRAY

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Lime prod. - limestone prim. crushing	32	Particulates	@ 0.016 gr/ft^3	"poor"				261
Typical performance		Particulates	@ 5 gr/ft^3, 60,000 cfm	96.3	$51,200,or $0.84/cfm	$16,700/yr Tot.: 0.075¢/$10^3$ ft^3	Gravitational spray tower	5
Typical performance		Particulates	@ 5 gr/ft^3, 60,000 cfm	93.5	$24,400, or $0.42/cfm	$8,800/yr Tot.: 0.028¢/$10^3$ ft^3	self-induced spray (actually a scrubber)	5
Steel prod., blast furnace	33	Particulates	@ 3-4 gr/ft^3	99.3 (based on grain count)			Multiple sprays (in series)	15
Electric power gen., coal; spreader, chain grate, vibrating stokers	49	Particulates		60			Stack spray	16
Electric power gen., coal; spreader, chain grate, other stokers	49	Particulates		80			Stack spray	16

MEDIUM: AIR

TABLE 31 (cont.)
CONTROL METHOD: AFTERBURNER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Meat smoking	20	CO, HC		~100			Direct-fired afterburner	97
Gray iron foundry	33	Org. gases inorganic gases	@ 3 lb/hr @ 30 lb/hr	97	$2000 for 8T/hr plant	$200/yr		45
Airblown asphalt system	29		(See under "cap cost")		$3000 for 500 bbl/bath oper.			96
Aluminum prod., chip dryer	33		(See under "cap cost")		$3000 for 2.5 K lb/hr oper.			96
Coke oven	33		(See under "cap cost")		$1500 for 8' x 8' x 12' unit			96
Debonder	--		(See under "cap cost")		$300 for 500 brake shoes/hr. oper.			96
Food prep., deep fat fryer	58		(See under "cap cost")		$1500 for 1000 lb/hr oper.			96
Incinerator, drum reclamation	49		(See under "cap cost")		$2000 for 60 bbl/hr unit			96
Incinerator, drum reclamation	49		(See under "cap cost")		$5000 for 200 bbl/hr unit			96
Incinerator, flue-fed	49		(See under "cap cost")		$2500 for most sizes			96

TABLE 31 (cont.)

MEDIUM: AIR

CONTROL METHOD: AFTERBURNER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Lithography, oven	27		(See under "cap cost")		$15,000 for 240 ft/min unit			96
Type metal prod., pot furn.	33		(See under "cap cost")		$3,000 for 16,000 lb furnace			96
Varnish cooker	28	Org. gases	(See under "cap cost")		$5,500 for 500 gal. unit			96

TABLE 31 (cont.)

MEDIUM: AIR CONTROL METHOD: MISCELLANEOUS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Bulk gasoline loading rack	51	Org. gases (HC)	(See under "cap cost")		$50,000 for 667 K gal/day operation		Vapor control sys.; L. A. County	96
Petroleum refinery; crude oil distillation unit	29	Org. gases (HC)	(See under "cap cost")		$10,000 for 37 K bbl/hr operation		Vapor control sys., L.A. County	96
Gasoline storage, fixed-roof tank	51	Org. gases (HC)	(See under "cap cost")		$132,000 for 80 K bbl tank		Floating -roof tank, replacement for fixed-roof tank costing $50,000	96
Petroleum refinery, fluid c.c. unit	29	CO	(See under "cap cost")		$1,770,000 for 40 K bbl/day unit		CO boiler	
Oil-water separator	29	Org. gases (HC)	(See under "cap cost")		$80,000 for 300 K bbl/day unit		Floating roof	96
Oil-water separator	29	Org. gases (HC)	(See under "cap cost")		$700 for 350 bbl/day unit		Cover	96
Oil-water separator	29	Org. gases (HC)	(See under "cap cost")		$8,000 for 3,500 bbl/day unit		Floating roof	96
Sewage treatment headworks	49	Odoriferous gases	(See under "cap cost")		$20,000 for 250 M gal/day plant		Covers	96
Electric power gen., coal-fired	49	SO_2	(See under "cap cost")	67	$1.00/KW for 800 MW plant, amort. @ 14% int., limestone @ $2.00/T delivered, waste disp. & hauling @ $0.80/T net.		Limestone injection into furnace	12

TABLE 31 (cont.)

MEDIUM: AIR CONTROL METHOD: MISCELLANEOUS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Electric power gen., coal-fired	49	SO_2	(See under "cap cost")	90	$1.00/KW for 800 MW plant, amort. @ 14% int., limestone @ $2.00/T delivered, waste disposal & hauling @ $0.80/T net.	$1.15/T	Limestone injection into furnace	12
Air transportation, turbine*	45	Particulates		15			Ethyl Corp. "CI-2" additive (to regular turbine 'A" fuel)	266
Air transportation turbine*	45	NO_2		10 increase			Ethyl Corp. "CI-2" additive (to regular turbine "A" fuel)	266
Air transportation turbine*	45	HC and org. gases, CO, SO_x		0			Ethyl Corp. "CI-2" additive (this and above two based on P. and W JT3D-3B)	266
Air transportation turbine*	45	Particulates		35			JP-4 fuel; substitute for regular turbine "A" fuel based on P and W JT8D-1	266
Air transportation turbine*	45	CO		20 increase			JP-4 fuel; substitute for regular turbine "A" fuel based on JT8D-1	266

*Emission changes computed in terms of lbs. pollutant/ave. flight

MEDIUM: AIR

TABLE 31 (cont.)

CONTROL METHOD: MISCELLANEOUS

Source	Code	Pollutant Removed	Capucity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Air transportation turbine*	45	NO_2		4 increase			JP-4 fuel; substitute for regular turbine "A" fuel based on JT8D-1	266
Air transportation turbine*	45	HC and org. gases		80			JP-4 fuel; substitute for regular turbine "A" fuel based on JT8D-1	266
Air transportation turbine*	45	SO_x		30			JP-4 fuel; substitute for regular turbine "A" fuel based on JT8D-1	266
Air transportation turbine*	45	Particulates		23			Use of "smokeless" burner cans, P and W JT8D turbofan	266
Air transportation turbine*	45	CO		20			Use of "smokeless" burner cans, P and W JT8D turbofan	266
Air transportation turbine*	45	NO_2		40 increase			Use of "smokeless" burner cans, P and W JT8D turbofan	266
Air transportation turbine*	45	HC and org. gases		99			Use of "smokeless" burner cans, P and W JT8D turbofan	266

*Emission changes computed in terms of lbs. pollutant/ave. flight

TABLE 31 (cont.)

MEDIUM: AIR CONTROL METHOD: MISCELLANEOUS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref.
Air transportation turbine*	45	SO_2		[illegible]			Use of "smokeless" burner cans, P and W JT8D turbofan	266
Elec. power gen., coal-fired	49	NO_x		62			Two-stage combustion with low excess air	44
Elec. power gen., coal-fired	49	Particulates		65–85 compared to pulverized firing			Cyclone firing; alternative to pulverized firing	44
Elec. power gen., coal-fired	49	Particulates		(See under remarks)			Higher sulfur-content coal; improves elec. pptr perf.	44

*Emission changes computed in terms of lbs pollutant/ave. flight

TABLE 32
WATER TREATMENT LIST

MEDIUM: WATER

TREATMENT METHOD: SCREENING

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost ($)	Remarks	Ref
Leather Tanning & Finishing	3111	BOD SS	-	5 5-10	4,000-25,000	300-3,000/ yr	Range of values for a plant processing 700 hides/dry	73
Synthetic Finishing Textile	2262	BOD SS	-	0-5 5-20	500-4,800	100-500/yr	Range for a plant processing 20,000 lb/ day	227
Cotton Finishing Textile	2261	BOD SS	-	0-5 5-20	6,000-30,000	2,000-5,000/yr	Range for a plant processing 50,000 lb/ day	227
Wool Finishing Textile	2231	BOD SS	-	0-10 20	1,300-6,000	300-600/yr	Range for a plant processing 20,000 lb/week	227
		SS		70			Microstraining	
Municipal Sewage	4952		10 mgd		440,000	65¢/ 1,000 gal	Secondary effluent @ 1967 $	112
			21 mgd		2.07/capita	17¢/capita/ yr	1968 $	122
		SS BOD	70 50					122

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: ACTIVATED SLUDGE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
Cannery waste	2033	BOD Total Carbon	10 mgd	90 80		7¢/1000 gal w.w.	With gravity settling before & aerobic digestion after (1967 $)	228
Citrus waste	2033	BOD	-	95.6	-	.95¢/lb BOD removed	Extended aeration modification	229
Cannery effluents	2033 2037	BOD SS	8 mgd	90	550,000	58,000/yr	BOD load [illegible] 100 mg/l	230
Cannery waste	2033	COD SS	969,900 gal/day	90 95	287,435	42,000/yr	Two-stage process	231
Citrus waste	2037	BOD	-	-	-	3.2¢/lb BOD removed	Sludge used in cattle feedlot	232
Motor vehicles Body assembly & Final assembly	371	BOD SS	- -	80-95 85-95	- -	- -	A.S. proceeded by chem. clarification	233
Brewery waste	2082	P	-	95.7	-	-		234
Mfg. of vinyl chloride polymers	28212	BOD	-	88	-	-	Total treatment with activated sludge	235

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: ACTIVATED SLUDGE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost ($)	Remarks	Ref
Leather Tanning & Finishing	3111	BOD SS Chromium Sulfide	-	85-95 80-95 75 75-100	75,000-200,000	3,000-16,000/yr	Range for a plant processing 700 hides/day	73
Wool Finishing	2231	BOD SS	-	85-90 90-95	14,000-39,000	2,300-6400/yr	Range for a plant processing 20,000 lb/week	227
Cotton Finishing	2261	BOD SS	-	70-95	5,400-29,000	800-4800/yr	Range for a plant processing 20,000 lb/day	227
Pulp Mill Effluent	2611	SS BOD	54 mgd	78 91	31,127,000	3,087,000	Includes 30 mgd of municipal sewage	110
		BOD SS	-	85-95 85-95	-	-	Preceded and followed by plain sedimentation	236
Municipal Sewage	4952		10 mgd	-	3.2×10^6	5¢/1,000 gal	1967 adjusted $	112
			10 mgd	-	2.8×10^6	5.3¢/1,000 gal	1970 adjusted $	237
		Brine w.w.	-	90-92	1.4×10^6	775,000/yr		

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: ACTIVATED SLUDGE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost ($)	Remarks	Ref
		BOD	<25 mg/l				Max. effluent quality attainable	238
		SS	<20 mg/l					
		N	.12 lb					
			.026 lb.					
					25-29/ capita	1.87-2.03/ capita/yr		122

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: TRICKLING FILTER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
Food Products whey effluent	2022	BOD	-	90	272/lb. BOD loading/day	-		239
Whey effluent	2022	BOD	1.17 mgd	-	1,924,300	114,300/yr	.7 lb. sludge produced per lb. BOD removed	240
Cannery waste	2033 2037	BOD	8 mgd	76	2,000,000	29,000/yr	BOD loading x 300 mg/l	230
Fruit Processing	2033	BOD	-	45	-	-	BOD loading = 580 lb/1,000 ft /day w/21.5 ft depth - plastic media	237
Leather Tanning & Finishing	3111	BOD SS Chromium Sulfide	-	65-80 85-90 25-75	50,000 - 150,000	3,000 - 10,000/yr	Range for a plant processing 700 hides/day	73
Wool Finishing	2231	BOD SS	-	80-95 90-95	11,000 - 26,000	1,600 - 3,900/yr	Range for a plant processing 20,000 lb/wt	227
Cotton Finishing Textile	2261	BOD SS	-	40-85 80-90	5,300- 12,000	10,000 - 24,000/yr	Range for a plant processing 50,000 lb/day	227

TABLE 32 (cont.)

TREATMENT METHOD: TRICKLING FILTER

MEDIUM: WATER

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
Synthetic Finishing	2261	BOD SS	-	40-85 80-90	4,200 - 19,000	600-2900/ yr	Range for a plant processing 20,000 lb/dry	227
		BOD SS	-	80-95 70-92	-	-	Preceded and followed by plain sedimentation	236
			10 mgd		3×10^6	2.8¢/1,000 gal	@ 1967 $	112
		BOD		85	29.46-45.14/ capita	1.23 - 1.94/ capita/yr		122

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: LAGOONS & STABILIZATION BASINS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Food Products	2013	BOD	-	82	-	39¢/1,000 lb. live wt Anaerobic lagoon	Meat packing waste 1970 $	241
Cannery effluents	2033 2037	BOD	8 mgd	90	648,000	68,000/yr	Aerated lagoon	230
Petrochem. waste	2911	BOD	10 mgd	54.5	33/lb.BOD/day 28/lb.BOD/day	0.034/lb. BOD .020/lb BOD	Anaerobic lagoon op. costs includes amortization of investment.	242
Subsurface Ag. waste	01	Nitrate	-	70-85	135/mill. gal. waste	-	Algal growth & 95% harvest	243
Leather Tanning & Finishing	3111	BOD SS Chromium	-	70 80 10-20	5,000-10,000	200-1,300/yr	Lagoons for a plant processing 700 hides/day	73
Synthetic Finishing	2262	BOD SS	-	50-95 50-95	1,200 -7200	400-2,200/yr	Aerated lagoon for a plant processing 20,000 lb/day	227
Cotton Finishing	2261	BOD SS	-	50-95 50-95	15,000-45,000	6,000 - 18,000/yr	Aerated lagoon for a plant processing 50,000 lb/day	227

MEDIUM: WATER

TABLE 32 (cont.)

TREATMENT METHOD: LAGOONS & STABILIZATION BASINS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Wool Finishing	2231	BOD SS	-	0-85 30-70	1,000-3,200	200-300/yr	Lagooning for a plant processing 20,000 16/week	227
Pulp Mill Effluent	2611	BOD	17 mg	80-95	665,000	111.20/mg Waste water treated	Aerated lagoon 4 mgd from the mill Td=8 days	244
		BOD	1 mgd	70	Land=2,050 Other=80,019	8,324/yr	Aerated lagoon area = 2.05 acres	245
Petro-chemical Waste	29	BOD	10 mgd			3.4¢/lb BOD removed	Anaerobic lagoon	246
		BOD	1 mgd	70	Land=8,060 Other=115,966	8,475/yr	Anaerobic lagoon	245
		BOD		<50 mg/l >50 mg/l			Aerated lagoons Max.effluent quality attainable	23
					5.23-21.42/capita	0.22-0.67/capita/yr	@ 1968 $ Aerated lagoon	245
		BOD SS		>100 mg/l <100 mg/l			Anaerobic lagoon max. effluent quality attainable	238

TABLE 32 (cont.)

MEDIUM: WATER TREATMENT METHOD: CHEMICAL ADDITION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Rinse Water from Steel Pickling	3312	Fe	1500 gpm	99	1,360,000	4.38¢/fin steel-24¢/1,000 gal w.w.	Limestone neutralization plus aeration	247
Coal Mning Acid Mine Drainage	12	Iron		99		Chemical costs 0.32/1,000 gal.	Using: Lime	
			-	96.2	-	0.35-.059/1,000 gal.	Limestone	
				97.2		.268/1,000 gal.	Soda Ash	248
		Acidity (cold)		99.5		.032/1,000 gal.	Lime	
			-	90.0	-	0.35-0.57/1,000 gal.	Limestone	
				100.0		.268/1,000 gal	Soda Ash	
Pulp & Paper Waste	26	COD $PO_4^=$ S.S.	10 mgd	70 90 40-80	.05/1,000 gal	op. = 5¢/1,000 gal chem = 6¢/1,000 gal.	300-400 mg/l of $FeCl_2$ M Alum coagulant under 175 psi Air/water = .17/1 for foamy waste water	249

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: CHEMICAL ADDITION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
Leather Tanning & Finishing	3111	BOD SS Chromium Sulfide	-	41-70 70-97 50-30 14-50	20,000 - 160,000	3,000 - 15,000/yr	Chem. coagulation & ppt. for a plant processing 700 hides/day	73
Synthetic Finishing Textile	2261	BOD SS	-	25-60 30-90	2,400 - 9,600	1,200- 4,800/yr	Chemical ppt.for a plant processing 20,000 lb/day	227
Cotton Finishing Textile	2261	BOD SS	-	25-60 30-90	30,000 - 60,000	20,000 - 40,000/yr	Chem. ppt. for a plant processing 50,000 lb/day	227
Wool Finishing Textile	2231	BOD SS	-	40-70 80-95	6,400 - 13,000	3,200 - 6,400/yr	Chem. ppt.for a plant processing $CaCl_2$ 20,000/lb week	227
		BOD SS		50-85 70-90			Chem. ppt.	236
		P		88-95 95-98 (with filtration)		40-70/mg 70-90/mg		82
Municipal Sewage	4952	BOD COD PO_4	350 mgd	78 81 95	22,410,000 6.4¢/6 PO	3,759,000/ yr 5.8¢/ 1,000 gal		84

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: CHEMICAL ADDITION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Canning and Freezing Fruits & Vegetables	2033 2037	BOD SS				18,000/yr 1.30/ton of raw product	Flocculation	250
		BOD SS PO_4 N	7.5 mgd		5.97/capita	5.2¢/1,000 gal. 97¢/ capita/yr	Chem. coagulation using lime @ 1968 $	122
		SS PO_4		< 10 mg/l < 1 mg/l			Chem. ppt. max. effluent quality attainable	238

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: STRIPPING TOWERS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
		NH_3	7.5 mgd	>95		0.9¢/1,000 gal.	Max. effluent quality available	238
		NH_3	10 mgd		320,000	1.0¢/ 1,000 gal.	@ 1967 $	122
		NH_3	≥ 1 mgd		6.37/capita	79¢/capita/ yr	@ 1968 $	122
		NH_3		80-90		8.80-25.00/ mg		82
		NH_3		80-95		1-3¢/1000 gal.		129

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: SEDIMENTATION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Blast Furnace & Cinter Pit	3312	S.S.	-	93.8	-	-	Plain sed.	251
Hot Rolling Mills		S.S.	-	90.7	-	-	Plain sed.	
Plant Furnace & Cinter Pit		S.S.	-	98.2	-	-	Sed. & coagulation	
Hot Rolling Mills		S.S.		95.4	-	-	Sed. & coagulation	
Cold Mills		S. S.	-	50.0	-	-	Sed. & coagulation	
Mfg. of Vinyl Chloride Polymers	28212	BOD SS		< 1 98	-	-	Primary clarification	235
Leather Tanning & Finishing	3111	BOD SS Chromium Sulfide	-	25-62 69-96 5-30 5-20	20,000 - 40,000	1,000-3,000/yr	Range of values for a plant processing 700 hides/day	235
Wool Finishing Textile	2261	BOD SS	-	30-50 50-65	2,900 - 8,000	500-1,300/yr	Range for a plant processing 20,000 lb/week	227
Cotton Finishing Textile	2261	BOD SS	-	5-15 15-60	14,000 - 38,000	3,000 - 8,000/yr	Range for a plant processing 50,000 lb/day	227
Synthetic Finishing Textile	2262	BOD SS		5-15 15-60	1,100 - 9,000	100 - 1,000/yr	Range for a plant processing 20,000/day	227

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: SEDIMENTATION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost ($)	Remarks	Ref
		BOD		10-30	18.53/capita			
		SS		50-90				
			10 mgd		1.8×10^6 15¢/1,000 gal.	3¢/1,000 gal.	@ 1967 $	122
					16.04-17.75/ capita	1.32-1.41/ capita/yr	@ 1968 $	122
Potato Processing Wastes	2037	BOD		41			Primary clarifier	279
		SS		73				
		Kjeldahl N	800 gal/day	21				
		PO_4		21				

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: FLOTATION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost ($)	Remarks	Ref
Edible Fat & Oil Refinery Wastes	20	SS	-	87-92	-	656/1 mgd wasteflow	Alum. dosage = 100-700 ppm Oil recovery = $342/1 gpd pH = 3.5-6.0	121
		BOD		74-81				
Wool Finishing Textiles	2231	BOD	-	30-50	3,500 - 10,000	600 - 1,600/yr	Range for a plant processing 20,000 lb/week	111
		SS		50-65				
		BOD		10-30				
		SS		70-95				

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: ELECTRODIALYSIS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
		Inorganic Salts	10 mgd	40		16¢/1,000 gal.	Pretreatment & residue disposal not included in the cost	
			10 mgd		2,500,000	8.75¢/ 1,000 gal		
				40		15¢/1,000 gal.		
		N	1 mgd-10 mgd	30-50		130-210/ mg	Solids conc = 1,000 ppm	82
		Inorganic salts		10-40		25-75¢/ 1,000 gal		129

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: ACTIVATED CARBON

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost ($)	Remarks	Ref
Textile Dye Waste Water	226	COD	1 mgd	85	550,000	23.1¢/ 1,000 gal.	Carbon is regenerated biologically	252
Electroplating waste	3471	Hexauatent Chromium Total Chromium	-	99 95	-	5.00/day for 15 gpm waste stream	Waste stream contains 100 ppm of Hexaulent Cr. method employs caustic regeneration	216
		BOD SS Sulfide	10 mgd	50–90 90 80–99	1.6 x 10^6	5.3¢/ 1,000 gal.	@ 1967 $	122
			$\geq$ 1 mgd		14.36/ capita	2.95/yr/ capita		122
		BOD N	1–2 gal/min per ft^3 carbon	98				83
				90–98		4–8¢/ 1,000 gal		129
Electroplating waste	3471	Heavy Metals	15 gpm	99		5/day	Heavy metals = 100 ppm Removal includes recovery. Employing caustic regeneration	253

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: ACTIVATED CARBON

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
Municipal Sewage	4952		350 mgd		39,439,000 16.7¢/gpd	6,116,000/ yr 95¢/ 1,000 gal.	@ 1969 \$ Projected data	84
		SS BOD		90 85				84
		BOD SS		< 2 mg/l <1 mg/l		4.2¢/1,000 gal.	Max. effluent quality attainable	238

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: ION EXCHANGE

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost($)	Remarks	Ref
		SS N PO_4 TDS	3 mgd	<1 mg/l		15¢/1,000 gal.	Max. effluent quality attainable - cost includes resin regeneration with acid & methanol	238
		N		80-92		170-300/mg	Eff. & cost dependent on pretreatment	82
						17-25¢/ 1,000 gal		129
		Organic Matter	3 gal/min/ ft^3				for 5 mg/l organics	83
			2 gal/min/ ft^3				5-20 mg/l organics	
			1 gal/min/ ft^3				20 mg/l organics	
Mine Drainage	12					.30-2.53/ 1,000 gal	Cost depends on plant size, TDS conc, ion exchange scheme	254
Municipal Sewage	4952	NH_3	350 mgd	82	9,518,000 5.6¢/1000 gal.	4,088,000/ yr	Projected for year 2000	84
Municipal Sewage	4952	NH	7.5 mgd 10 mgd	93-97 93-97		9.04¢/1,000 gal. 8.5¢/1,000 gal.	Electrolytic regeneration Air stripping regeneration	85

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: REVERSE OSMOSIS

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost($)	Operating Cost ($)	Remarks	Ref
Metal Finishing	3471	Cu SO_4	-	99.8	-	-	Using ultrathin cellulose acetate membrane	255
Nickel Plating	3471	Nickel	-	98.9-99.7	-	-	Using porous cellulose acetate membrane	256
Pulp and Paper Mill Effluent	2611 2621	-	1 mgd	90-99	1,000,000	1.32-2121/ 1,000 gal. of permate water		257
		TDS		65-95		25-40¢/ 1,000 gal.	Limited usefulness with nitrate ions	129
Mine Drainage	12					0.68-2.57/ 1,000 gal.	Cost depends on size of plant	254

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: SPRAY IRRIGATION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost	Operating Cost	Remarks	Ref
Cannery effluent	2033 2037	BOD N P	120 acres	99 90 90	30,000 and land cost	40,000/yr	100 inches of waste/yr spraying on slope draining to lagoons	230

TABLE 32 (cont.)

MEDIUM: WATER

TREATMENT METHOD: CHLORINATION

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost ($)	Remarks	Ref
Municipal Sewage	4952		10 mgd		68,000	.69¢/ 1,000 gal	Secondary effluent @ 1967 $	112

MEDIUM: WATER

TABLE 32 (cont.)
TREATMENT METHOD: DISPOSAL

Source	Code	Pollutant Removed	Capacity	% Efficiency	Capital Cost ($)	Operating Cost($)	Remarks	Ref
					2-2.50/ft^3	4-18/ft^3	Anaerobic digestion	
					5-10/ton	4-9/ton	Incineration	
						20/ton	Wet oxidation	
						8-32/ton	Vacuum filtration cost increases with chem. addition	

SECTION VII
REGULATORY CONTROL STRATEGY

INTRODUCTION

In general, regulatory measures are more likely to create intermedial pollution transfer through inadvertence than by design. Recognition of environmental protection as an indivisible problem is a relatively recent development. Creation of the Environmental Protection Agency, the first major Federal agency responsible for comprehensive environmental-control strategy, and passage of the National Environmental Policy Act are evidence of the new awareness. The purpose of this chapter is to summarize the major regulatory control legislation strategies, and their intermedial impacts.

For the purpose of this study, strategy may be defined as the art or science applied in support of national policy to reduce or eliminate intermedial pollution. The nation's environmental policy is defined by the 1969 National Environmental Policy Act (NEPA),[335] the Clean Air[336] and Clean Water Acts,[337] and all related court decisions. National environmental policy is established as the result of legal process (legislative and judicial), but the same legal process also defines the basic strategic elements which are then administered by the designated agency (ies) or official(s). Regulatory control strategy implements established policy within a legal framework or system which includes governmental agencies or entities at the National, State, regional, and local levels as well as codes, standards, economic strategies, land-use restrictions, and enforcement procedures.

The courts stand in a pivotal relation between policy and strategy. Although they help to make both policy and regulatory strategies precise through interpretation of the law, judicial decisions may also translate policy into strategic applications not envisioned by the responsible agency. The so-called "Friends of Mammoth," California, and similar decisions to require environmental-impact studies for new private construction projects in the State of California are examples of judicial action with major strategic impact.

It is the regulatory agencies, however, which are responsible for developing and enforcing the strategies which convert legal intent into functional reality. Through legal action they stimulate technological control. Technological control includes all physical/process means which implement policy, while regulatory control includes all legal means which implement technological objectives. The approved automotive engine illustrates technological control; the requirement for its approval prior to the manufacture and sale of automobiles illustrates regulatory control. The regulatory agencies and their functions, however, are not isolated from the society as a whole. Activities of the courts, concerned individuals, special-interest citizens' groups, and various institutions, political or otherwise, may support, modify, and influence the regulatory agencies' perceived or mandated objectives.

Major interfaces between regulatory control activities and intermedial pollutant transfer problems may occur as the result of: concurrent imposition of ambient air and water standards; regulation of permissible composition and quantity of effluents discharged into the environmental media; environmental-impact study requirements; definition of the processes, treatments, and land uses permitted or proscribed by the responsible agencies; and the exercise of intermedia management. Without comprehensive impact-analysis, however, the net effect of regulatory strategies may include undesirable intermedial pollution transfer. The potential effect of implementing the proposed congressional goal of zero-pollution discharge to the nation's waterways by 1985 illustrates this difficulty.

In his testimony before the House Committee on Public Works, Dr. Joseph T. Ling, Director of the Environmental Engineering and Pollution Control Department at the Minnesota Mining and Manufacturing Company, projected the environmental cost-benefits associated with zero water-pollution discharge (based on drinking water standards) from one of the company's plants. In order to remove 4,000 tons of water pollutants, he estimated the company would have to purchase the equipment, concrete, and steel to construct a $25 million waste-removal facility; 9,000 tons of chemicals including sulphuric acid and caustic carbon; 1,500 kw of electricity; and 19,000 tons of coal. Based on the use of these materials, he further estimated that the waste-removal operations would produce about 9,000 tons of chemical sludge, 1,200 tons of fly ash, 1,000 tons of sulphur dioxide, and 200 tons of nitrogen oxide. Including the related waste yield produced by the original suppliers of the materials, he calculated that the total environmental impact of removing 4,000 tons of water pollutants would be the production of some 19,000 tons of solid waste and air pollutants. Dr. Ling concluded that " . . . the zero discharge based on this particular operation would produce a negative environmental impact."[338]

The accuracy of the preceding analysis is not at issue. Dr. Ling's testimony is introduced to demonstrate the importance of a holistic approach to environmental protection. Two factors compound the difficulty: environmental impact studies are frequently directed toward a limited physical area, and regulatory agencies are normally concerned with only one environmental medium at a time. There is frequently, therefore, no obvious mechanism through which the larger areal intermedial impacts can be evaluated and controlled.

Zero pollution discharge to the Nation's waterways is a desirable goal, but Dr. Ling's testimony raises many questions: What effluent standards meet the criterion of zero discharge? Was the waste-removal plant using the optimum control system? Could the wastes have been alternately disposed to land or treated in such manner as to minimize environmental impact? Were alternate processes available in the manufacture of the original product? If the product cannot be manufactured without environmental degradation, should its production be permitted and, if so, at what cost to the public health and welfare? In other words, what are the total environmental and economic cost-benefits of alternative disposal, treatment, and production processes, and how can regulatory control optimize the decision-making procedure in the selection of these processes?

Another example of the need for comprehensive planning occurred when environmentalists successfully averted construction of a hydroelectric plant in the Grand Canyon. According to an editorial in the Wall Street Journal (August 1, 1972), the Four Corners power plant near Farmington, New Mexico, which was substituted to meet the area's power needs, ". . .uses coal and spews fly ash over the scenic landscape of that area."

Major recent Federal legislation to enable comprehensive planning, implementation, and enforcement of anti-pollution controls includes the National Environmental Policy Act of 1969,[335] the Clean Air Amendments of 1970,[336] the Federal Water Pollution Control Amendments of 1972,[337] and the Marine Protection, Research, and Sanctuaries Act of 1972.[340]

POLLUTERS AND THE INSTITUTIONAL FRAMEWORK

Pollution Sources Figures 20 and 21 schematically illustrate the restrictions and the options open to waste generators within the general framework of current laws and regulatory agencies. The figures illustrate the intermedial nature of the problem. The potential air pollution generator is defined as the institutional source, and is shown at the bottom of the diagram. The polluter may choose to comply with the air quality regulations or not. If the polluter complies, then there is the choice of also complying with the water quality regulations or of violating them with the pollutants removed from the air. If the polluter chooses violations he may be affected by the entire legal/enforcement framework shown in the upper half of the figure. Information flows from plant inspection and air monitoring points to the local, State and Federal protection agencies involved. They in turn have available to them the enforcement mechanisms shown on the chart. Thus the air polluter can compare the relative costs of each option and choose the optimal path for him. In the case of non-compliance the costs to the polluter will be the penalties imposed multiplied by the probability of being cited. This possibility of undetected non-compliance is an important consideration. The basic options open to the potential water polluter are essentially the same.

Figure 22 describes the policy and strategy elements as they are used in this report. Policies are set by legislative processes influenced by judicial processes. Judicial processes may affect strategy as well as policy through litigation between the control agencies and the pollution sources. From the policy, strategy elements are derived. These include: (1) the authority delegation necessary to implement the policy, (2) ambient standards to quantify the policy, (3) performance standards to achieve the ambient standards or directly achieve the policy, and (4) the legal, economic, and educational mechanisms to enforce the policy and strategy elements. These four elements then make up the regulatory control strategies which affect or control the technological controls implemented by the pollution sources to physically eliminate the pollution or to shift it to other media.

The Federal, State and local governments may be involved at both the policy and strategy levels of pollution control. For air pollution, the State and local role is largely limited to strategy except that States may choose to implement policies more stringent than the Federal policy. For water and land the State and local governments play a much stronger role at the policy level.

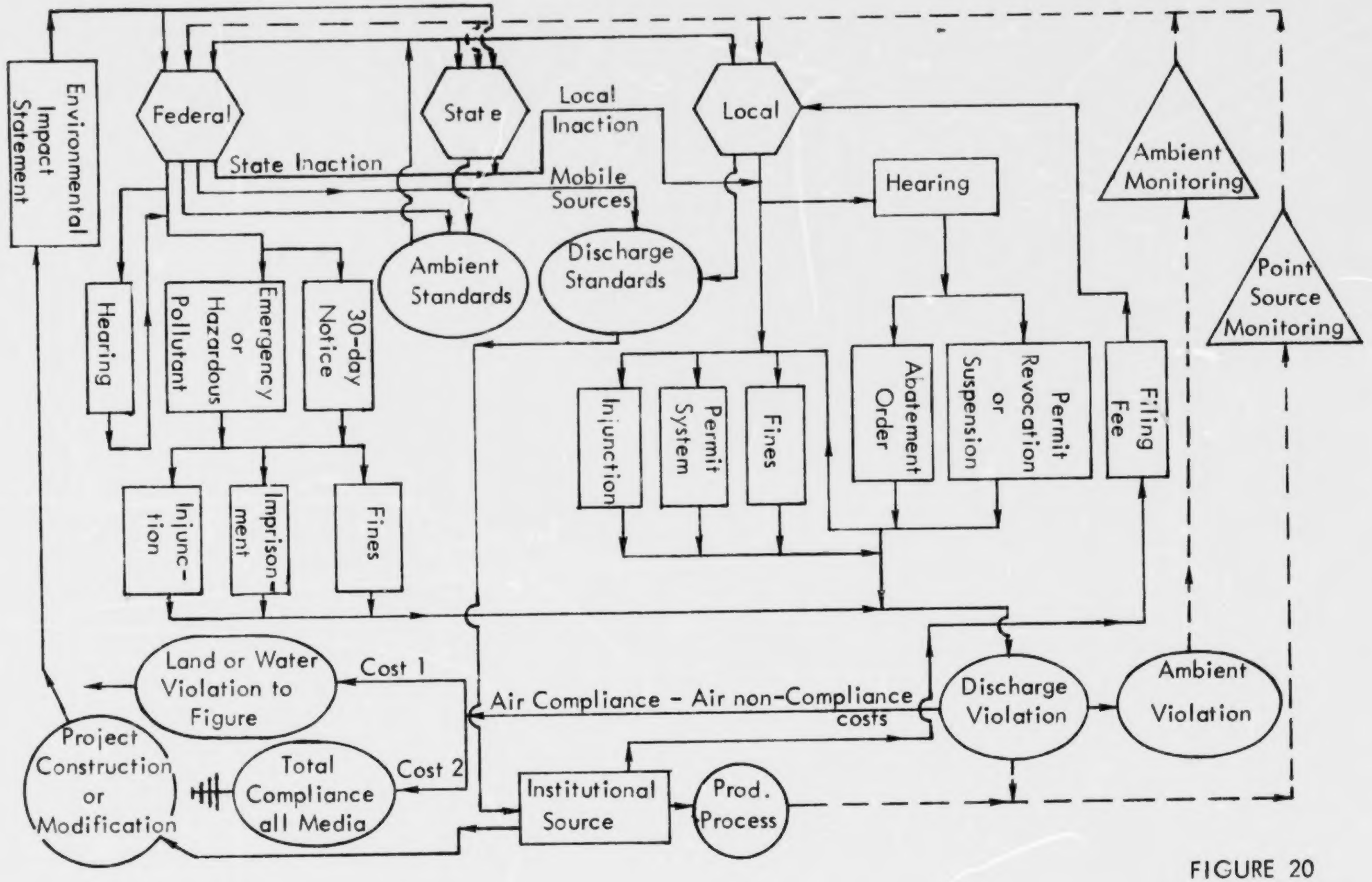

Environmental Impact Statement
Federal
State
Local
State Inaction
Local Inaction
Mobile Sources
Ambient Standards
Discharge Standards
Hearing
Emergency or Hazardous Pollutant
30-day Notice
Injunction
Imprisonment
Fines
Injunction
Permit System
Fines
Hearing
Abatement Order
Permit Revocation or Suspension
Filing Fee
Ambient Monitoring
Point Source Monitoring
Land or Water Violation to Figure
Cost 1
Air Compliance - Air non-Compliance costs
Discharge Violation
Ambient Violation
Project Construction or Modification
Total Compliance all Media
Cost 2
Institutional Source
Prod. Process

FIGURE 20
AIR POLLUTION
CONTROL SYSTEM

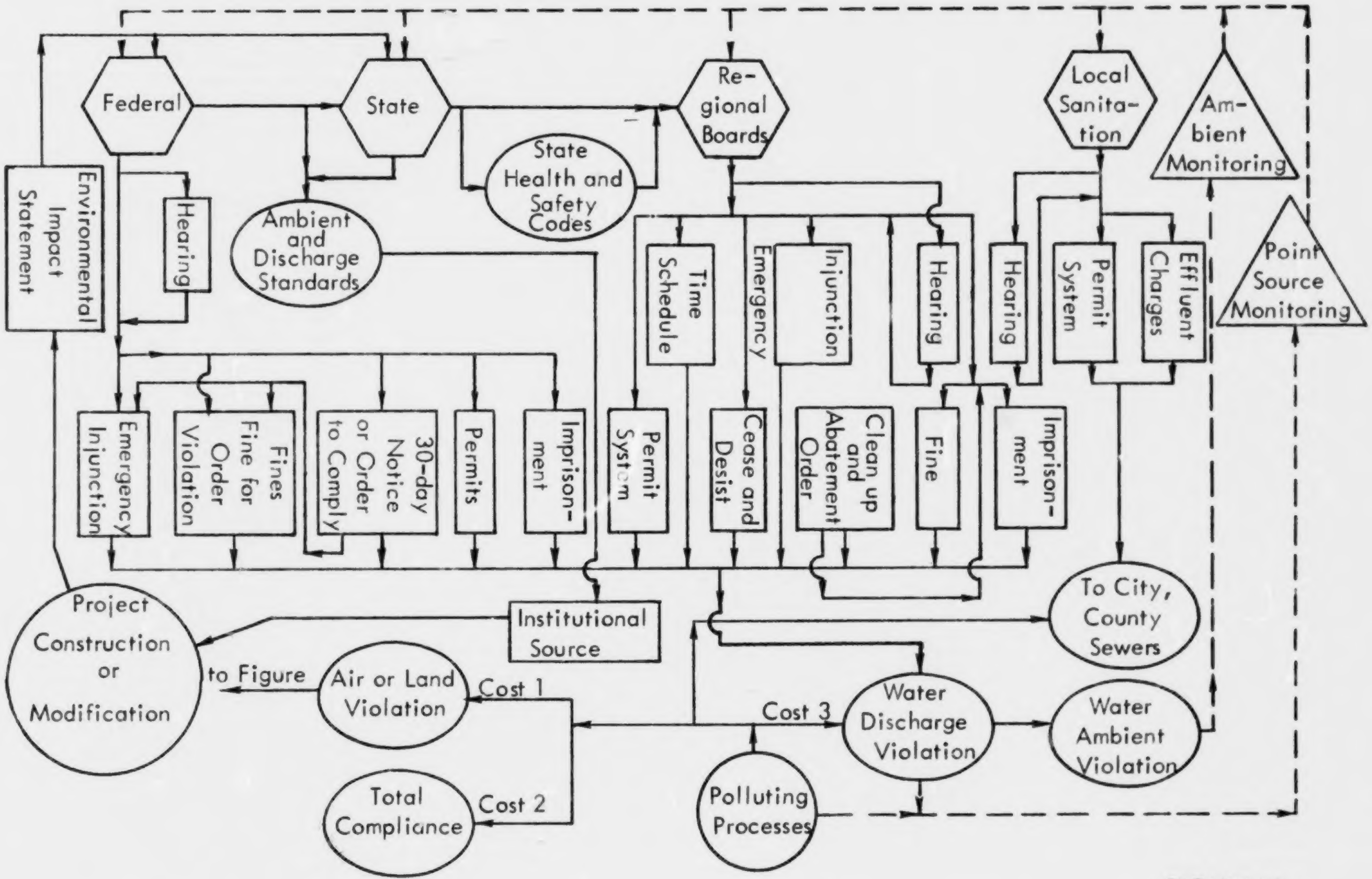

Federal
State
Re-gional Boards
Local Sanita-tion
Am-bient Monitoring
Point Source Monitoring
Environmental Impact Statement
Hearing
Ambient and Discharge Standards
State Health and Safety Codes
Time Schedule
Emergency
Injunction
Hearing
Hearing
Permit System
Effluent Charges
Emergency Injunction
Fines Fine for Order Violation
30-day Notice or Order to Comply
Permits
Imprison-ment
Permit System
Cease and Desist
Clean up and Abatement Order
Fine
Imprison-ment
Project Construction or Modification
Institutional Source
To City, County Sewers
to Figure
Air or Land Violation
Cost 1
Cost 3
Water Discharge Violation
Water Ambient Violation
Total Compliance
Cost 2
Polluting Processes

FIGURE 21
WATER POLLUTION
CONTROL SYSTEM

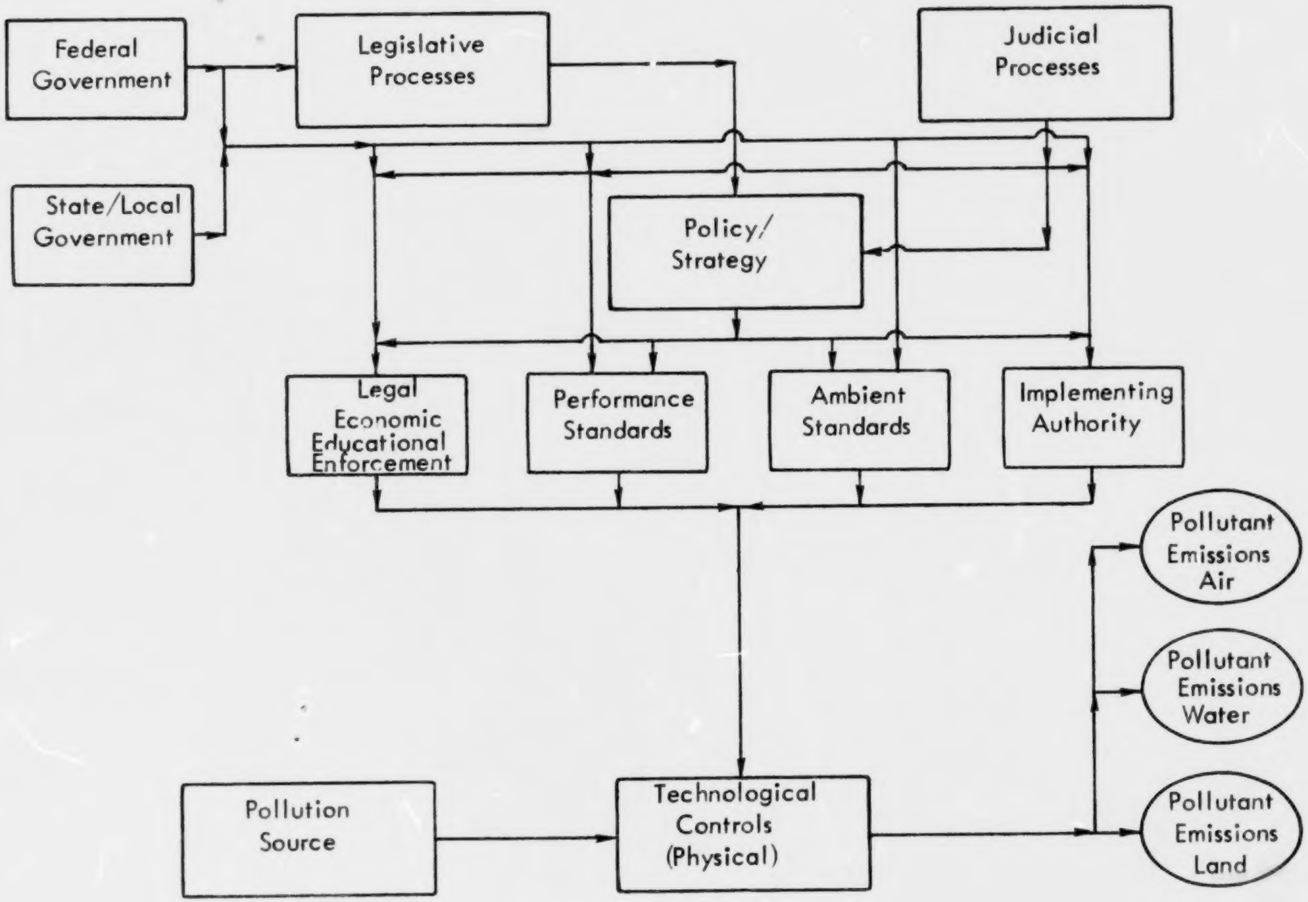

Federal Government
Legislative Processes
Judicial Processes
State/Local Government
Policy/ Strategy
Legal Economic Educational Enforcement
Performance Standards
Ambient Standards
Implementing Authority
Pollutant Emissions Air
Pollutant Emissions Water
Pollution Source
Technological Controls (Physical)
Pollutant Emissions Land

FIGURE 22
INTERMEDIA POLLUTION CONTROL:
STRATEGY AND POLICY RELATIONSHIPS

ENVIRONMENTAL STANDARDS

Environmental standards to protect human health and safety or ecological systems are expressed in terms of ambient standards in the receiving air and water, usually in parts per million (ppm) or micrograms per cubic meter (ll g/m^3) for air in parts per million (ppm) or milligrams per liter (mg/l) for water. Where Federal, State, and local ambient standards conflict, polluters in a given state are regulated to achieve the stricter standard.

To achieve the ambient standards for any particular area, applicable discharge standards must be developed. The State of California, for instance, develops an Implementation Plan in consultation with the local areas in order to achieve the ambient standards.[299] These plans which provide specific regulations on the types of discharges allowed for the key pollutant sources, may vary for different areas in the State depending upon local or regional environmental problems. Ambient and discharge standards exist for both air and water.

The in-plant ambient standard, related to the Occupational Health and Safety Act (OSHA),[343] protects employees but allows the plant to disperse the emissions off the plant premises. In an area with many plants, this could result in high area ambient level without any single plant violating the regulations. Present standards, however, set overall ambient level standards and then derive discharge standards to meet them.

State Air Standards The State of California Air Resources Board has the primary responsibility for the development and implementation of a State air pollution control plan to be submitted to the EPA for approval. Its main responsibility is to develop concrete discharge control plans to achieve a specified ambient standard. It cooperates with the Air Pollution Control District (APCD) Boards established at the County level and grouped in Air Basins prescribed by the Board.

Table 33, taken from the State of California Implementation Plan for achieving and maintaining the National Ambient Air Quality Standards, lists the Federal and California ambient air standards.[299] The plan uses these standards to derive discharge control strategies by region within the State. Examples of discharge standards for Los Angeles County are summarized in Table 34.

TABLE 33
AMBIENT AIR QUALITY STANDARDS[299] APPLICABLE IN CALIFORNIA

Pollutant	Averaging Time	California Standards		Federal Standards[d]		
		Concentration[g]	Method[a]	Primary[b,g]	Secondary[c,g]	Method[e]
Photochemical Oxidants (Corrected for NO_2)	1 hour	0.10 ppm (200 $\mu g/m^{c}$)	Neutral Buffered KI	160 $\mu g/m^{c,h}$ (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hours	10 ppm (11 mg/m^{c})	Non-Dispersive Infrared Spectroscopy	-	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hours	-		10 mg/m^{c} (9 ppm)		
	1 hour	40 ppm (46 mg/m^{c})		40 mg/m^{c} (35 ppm)		
Nitrogen Dioxide	Annual Average	-	Saltzman Method	100 $\mu g/m^{c}$ (0.05 ppm)	Same as Primary Standard	Colorimetric Method Using NaOH
	1 hour	0.25 ppm (470 $\mu g/m^{c}$)		-		
Sulfur Dioxide	Annual Average	-	Conductimetric Method	80 $\mu g/m^{c}$ (.03 ppm)	60 $\mu g/m^{c}$ (0.02 ppm)	Pararosaniline Method
	24 hours	0.04 ppm (105 $\mu g/m^{c}$)		365 $\mu g/m^{c}$ (0.14 ppm)	260 $\mu g/m^{c}$ (0.10 ppm)	
	3 hours	-		-	1300 $\mu g/m^{c}$ (0.5 ppm)	
	1 hour	0.5 ppm (1310 $\mu g/m^{c}$)		-	-	

TABLE 33

AMBIENT AIR QUALITY STANDARDS[299]

APPLICABLE IN CALIFORNIA

Pollutant	Averaging Time	California Standards		Federal Standards[d]		
		Concentration[g]	Method[a]	Primary[b,g]	Secondary[c,g]	Method[e]
Suspended Particulate Matter	Annual Geometric Mean	60 $\mu g/m^c$	High Volume Sampling	75 $\mu g/m^c$	60 $\mu g/m^c$	High Volume Sampling
	24 hours	100 $\mu g/m^c$		260 $\mu g/m^c$	150 $\mu g/m^c$	
Lead (Particulate)	30 Day Average	1.5 $\mu g/m^c$	High Volume Sampling. Dithizone Method	-	-	-
Hydrogen Sulfide	1 hours	0.03 ppm (42 $\mu g/m^c$)	Cadmium Hydroxide STRactan Method	- -	- -	- -
Hydrocarbons (Corrected for Methane)	3 hours (6-9 a.m.)	-	-	160 $\mu g/m^c$ (0.24 ppm)	Same as Primary Standard	Flame Ionization Detection Using Gas Chromatography
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility[f] to 10 miles when the relative humidity is less than 70%		-	-	-

TABLE 33
AMBIENT AIR QUALITY STANDARDS[299]
APPLICABLE IN CALIFORNIA

Pollutant	Averaging Time	California Standards		Federal Standards[d]		
		Concentration[g]	Method[a]	Primary[b,g]	Secondary[c,g]	Method[e]

NOTES:

[a] Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

[b] National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).

[c] National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.

[d] Federal standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

[e] Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" to be approved by the EPA.

[f] Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

[g] Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury.

[h] Corrected for SO_2 in addition to NO_2.

TABLE 34
EXAMPLES OF ADOPTED RULES AND REGULATIONS[299]
SOUTH COAST AIR BASIN

COUNTY: Los Angeles

Rules and Regulations	Effective 1-1-71	Changes to 1-7-72
Disposal and Evaporation	≤1-1/2 gal/day of photochemically reactive solvent	
Architectural Coatings	Restricts use and sale of chemically reactive coatings	
Sulfur		
Sulfur Recovery Plants	Exempted	500 ppm SO_2, 10 ppm H_2S 200 lb/hr SO_2
Sulfuric Acid Plants	Exempted	500 ppm SO_2, 200 lb/hr SO_2
Sulfur Compounds	0.2% SO_2 by volume max.	
Sulfur Content of Fuels	≤50 gr/100 ft^3 gaseous fuels, ≤5% by wt. liq. or solid fuels	
Fuel Burning Equipment	New equipment limited to 200 lb /hr. SO_2	
Oxides of Nitrogen		
Fuel Burning Equipment	New equipment limited to 140 lb/hr	<225 ppm from combustion of gaseous fuels. <325 ppm from combustion of liquid or solid fuels.
Carbon Monoxide		0.2% by volume max.
Other Regulations		
Asphalt Air Blowing	Controls required for new equipment	Extended to include all equipment.
Reduction of Animal Matter	Requires temperatures ≥1200° F for at least 0.3 sec.	
Vacuum Producing Devices or Systems	Limits amount of organic material emitted.	
Fluorine Compounds	No	

Water Standards The Water Quality Act of 1965 authorized each State to set water quality standards subject to EPA approval. In order to help the States set these standards, the National Technical Advisory Committee on Water Control Criteria was formed. They provided not standards, but criteria on which standards could be based. The criteria are given according to use. The five categories are (1) Recreation and Esthetics; (2) Public Water Supply; (3) Fish, other Aquatic Life and Wildlife; (4) Agriculture; and (5) Industry. The suggested criteria for category (2), Public Water Supplies, are shown in Table 35.

While ambient air standards are set at the Federal level, water quality standards are primarily a State responsibility. The Federal laws are intended to aid achievement of the State Standards. The EPA, however, retains the authority to veto State plans.

Table 36 illustrates ambient water quality standards for dissolved oxygen in California waters. The 1969 California Water Quality Act gives the regional boards the authority to set discharge standards and the power to enforce them.

TABLE 35

FEDERAL SURFACE WATER CRITERIA FOR PUBLIC WATER SUPPLIES[210]

Constituent or Characteristic	Permissible Criteria	Desirable Criteria	Paragraph
Physical			
Color (color units)	75	10	1
Odor	Narrative	Virtually absent	2
Temperature*	do	Narrative	3
Turbidity	do	Virtually absent	4
Microbiological:			
Coliform organisms	10,000/100 ml[1]	100/100 ml[1]	5
Fecal coliforms	2,000/100 ml[1]	20/100 ml[1]	5
Inorganic chemicals: (mg/l)		(mg/l)	
Alkalinity	Narrative	Narrative	6
Ammonia	0.5 (as N)	0.01	7
Arsenic*	0.05	Absent	8
Barium*	1.0	do	8
Boron*	1.0	do	9
Cadmium*	0.01	do	8
Chloride*	250	25	8
Chromium* hexavalent	0.05	Absent	8
Copper*	1.0	Virtually absent	8
Dissolved oxygen	4 (monthly mean) 3 (individual sample)	Near saturation	10
Fluoride*	Narrative	Narrative	11
Hardness*	do	do	12
Iron (filterable)	0.3	Virtually absent	8
Lead*	0.05	Absent	8
Manganese* (filterable)	0.05	do	8
Nitrates plus nitrites*	10 (as N)	Virtually absent	13
pH (range)	6.0-8.5	Narrative	14
Phosphorus*	Narrative	do	15
Selenium*	0.01	Absent	8
Silver*	0.05	do	8
Sulfate*	250	50	8
Total dissolved solids* (filterable residue)	500	200	16
Uranyl ion*	5	Absent	17
Zinc*	5	Virtually absent	8

TABLE 35

FEDERAL SURFACE WATER CRITERIA FOR PUBLIC WATER SUPPLIES (cont)

Constituent or Characteristic	Permissible Criteria	Desirable Criteria	Paragraph
Organic chemicals: (mg/l)			
Carbon chloroform extract* (CCE)	0.15	0.04	18
Cyanide*	0.20	Absent	8
Methylene blue active substances*	0.5	Virtually absent	19
Oil and grease*	Virtually absent	Absent	20
Pesticides:			
Aldrin*	0.017	do	21
Chlordane*	0.003	do	21
DDT*	0.042	do	21
Dieldrin*	0.017	do	21
Endrin*	0.001	do	21
Heptachlor*	0.018	do	21
Heptachlor epoxide*	0.018	do	21
Lindane*	0.056	do	21
Methoxychlor*	0.035	do	21
Organic phosphates plus carbamates*	0.1[2]	do	21
Toxaphene*	0.005	do	8
Herbicides:			
2,4-D plus 2,4,5-T, plus 2,4,5-TP*	0.1	do	21
Phenols*	0.001	do	8
Radioactivity:	(pc/l)	(pc/l)	
Gross beta*	1,000	100	8
Radium-226*	3	1	8
Strontium-90*	10	2	8

---

* The defined treatment process has little effect on this constituent.

1 Microbiological limits are monthly arithmetic averages based upon an adequate number of samples. Total coliform limit may be relaxed if fecal coliform concentration does not exceed the specified limit.

2 As parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures. See para. 21.

TABLE 36

CALIFORNIA DISSOLVED OXYGEN STANDARDS[346]

Water Body	Dissolved Oxygen Standard
Freshwater streams and lakes	A minimum of 6 and 7 mg/l with additional limit of 80-85% saturation for some streams 90% saturation for Lake Tahoe
Estuarine waters	A minimum of 5 mg/l for most 6 to 7 mg/l for some bodies
Coastal waters	A minimum of 5 mg/l with additional limits on the annual mean average with ranges of from 6 - 7 mg/l.

REGULATORY STRATEGIES

Table 37 lists various mechanisms available to Federal, State, and local authorities to facilitate or enforce compliance with air, water and land environmental standards and regulations. The strategies have been classified as legal, economic, and educational/psychological according to their major impact.

Legal Strategies: Enforcement and Evasion

Even when stringent laws exist, their effect is unclear because of the problem of enforcement. The number of inspectors provided and their powers, how often each plant is sampled, and methods for evading the law, will all influence the laws' effectiveness. A few methods of evasion are discussed below.

Dilution This can be accomplished in air or in water. In air a common method is to construct additional stacks and provide more air throughout. Thus the same amount of pollutants are present in the emissions but in a form below the concentration standard for the particular pollutant. In water dilution is accomplished by using more process water. This is prohibited by law, but the restriction is difficult to enforce.

Sporadic Operation of Control Equipment Control equipment may be turned on only while the inspector is present. In the case of mobile sources, exhaust devices may be removed after the original inspection.

Night Discharges It is possible for some plants to store their wastes and discharge them into waterways at night. Where there are many plants on a particular waterway this technique is very difficult to control.

Fragmentation of Responsibility Many times the responsibility for pollution control is divided among so many agencies that it is possible for the polluter to escape "between" the agencies.

Conflict of Interest The law frequently requires industrial and "public" representation on pollution control boards. These requirements have been used in the past to influence policy through appointment of advocates of the industries they are supposedly controlling. An example in California is the organization of the former Water Quality Control Boards which resulted in passage of a State law preventing Board membership to any discharge permit holder. Additionally, this law requires approval of recommendations of Regional Boards by the State Water Resources Control Board.

In areas which are heavily dependent on a few key industries, law enforcement may be lax. Property assessment values may be lowered and sewer charges based on low discharge estimates. Other difficulties in legal enforcement include: the fragmented nature of both the laws and agencies, resulting in separate consideration of different media; inability or failure to impose comprehensive industrial/land use planning; and inadequate funding to carry out plans and programs.

TABLE 37

REGULATORY STRATEGY CLASSIFICATIONS

Legal	Economic	Educational/Psychological
Standards	Subsidies - grants tax write-off bond issue-financing loans awards	Policy statements
Comprehensive planning		Guidelines
Licensing/permit requirements		Research development, training programs
Impact statements	Procurement	Press releases and published reports on improved methods technology, hazards
Hearings	Civil Penalty-(fines)	
Injunction	Cleanup charges	Promotion
Data reports	Filing fees	Conferences
Inspection/monitoring	Licensing fees	Public identification of violators
Cleanup orders		
Abatement orders		Awards, other publicity for superior performance
Suspension and revocation		
Civil/criminal penalty-imprisonment-fines		
Citizen's suits		

Economic Strategies

When neither the primary source of a pollutant nor the major beneficiary of the related product or service assumes social or economic responsibility for the effect, the real cost of the pollutant becomes "externalized". In general, manmade environmental pollution has been an externalized cost, for, whether calculated as environmental degradation, health hazard, agricultural damage, or cleanup cost, the burden has been largely displaced to an external community.

Present legislation and stricter enforcement of both present and past regulatory restraints are intended to "internalize" pollution costs. Under the Clean Air Act, for example, the automotive industry must insure a product which meets specified emission standards. Given normal business practice, the cost of compliance will be borne initially by the automotive producer, and ultimately -- in whole or in part -- by the consumer. The cost of potential automotive pollution will then have been internalized within the related production-consumption cycle, and the real cost of that pollution may be said to equal the monetary cost of its elimination.

Internalizing the cost of pollution, whether generated by industry, a political entity, or an individual, serves three beneficial purposes: it is a strategy for pollution control at the source; it permits quantification of socioeconomic cost in monetary terms; and it encourages a more just distribution of actual cost. The function of economic strategy is to promote compliance with the government's environmental policy through the application of punitive or compensatory monetary incentives. The three criteria for evaluating economic strategy are: cost-effectiveness in reducing pollution load in the total environment; equitability of distribution of associated costs; and minimum economic dislocation.

Punitive

Fines for violating regulatory standards relating to emissions, equipment, or procedures.

Compensatory

Accelerated writeoff of pollution-control capital investment.

Exclusion from property tax of pollution-control fixed assets purchased to meet regulatory requirements.

Private-sector use of public bonding to finance pollution-control capital expenditure.

Preferential consideration for government contracts based on environmental impact.

Subsidies or grants to enable implementing desirable treatment/control (as in municipal sewage treatment plants, for example).

Low-interest government loans to help finance purchase of pollution-control equipment.

Special tax consideration or bonus payments for superior pollution-control performance.

Educational/Psychological Strategies

Although economic and legal persuasion exert great leverage on human affairs, man's conduct is also subject to educational, psychological, and ethical influences. Regulatory agencies can use these influences to further insure compliance with environmental laws and strategies.

Educational techniques include: 1) the dissemination of information concerning improved equipment, materials, and processes for construction, manufacture, consumption, and pollution control; byproduct and reclamation opportunities; the economic and technological cost-benefits of pollution prevention/elimination alternatives; and the effects of pollutants on human health, welfare, and economics; and also 2) the promotion of research, development, and training programs; data/information resources; and conferences for the purpose of sharing existing knowledge or to provide a forum for new ideas. Information can be made available through the new media, special television and film documentaries, governmental reports and publications, special communication with industrial and waste-treatment management, and the services of university, governmental, and other public service agencies which are sources of or repositories for current information.

Most people live within some sort of ethical framework or boundary which can readily accommodate an environmental ethic. Certain types of ethical appeal can therefore serve as psychological deterrents to activity not in the public interest. The power of such persuasion is most evident in times of emergency such as during World War II when metal cans were dutifully cleansed, flattened, and saved for collection, or during periods of threatened drought, when water consumption is voluntarily limited even without rationing.

Citizens may be rewarded for behaviors promoting compliance with the environmental ethic by publishing the names of environmentally cooperative or outstanding citizens, groups, factories, or political entities; granting environmental Oscars or scrolls; developing a governmental Seal of Environmental Approval; designing a flag or other identification bearing a special anti-pollution logo to honor factories, organizations, or jurisdictions for extraordinary performance or contribution; installing a plaque in an ecological Hall of Fame for the greatest anti-pollution contribution of the year. Equally important, as a psychological dissuader, would be making the identity of major violators of environmental protection regulations available to the news media.

Economic considerations can reinforce many of the psychological satisfactions/dissatisfactions implicit in the preceding strategies. Environmental honors or identification of products which meet superior standards are an excellent form of advertising, while identification with poor environmental performance can alienate the consumer.

Integrated Planning

The direct relationship between industrial development, land use, demographic trends, environmental concerns, health care, and the economy requires an agency with the motivation and authority to coordinate the related pollution control factors.

Figure 23 illustrates the problem. A production decision is made. This results in: (1) plant construction; (2) production of the material inputs for the desired production; (3) the use of labor, raw materials, and capital goods in the process of manufacturing the final product; and (4) consumption of the final product. All four of these interdependent factors generate pollution, yet they are frequently regulated as almost entirely independent activities.

Current Federal legislation recognizes the possibility of intermedial problems, primarily through EPA and impact statement review, and enables consideration of those problems in the in the Federal decision-making process. Their effective control, however, would also seem to require integrated systems management at the local and regional levels, with emphasis on regional control where feasible.

There is probably no element in regional planning which is totally unrelated to potential pollution types, quantities, or media. The regional decision-maker should therefore consider the environmental impacts of all planning elements to evaluate their total intermedial effect. This type of comprehensive planning could then become a regulatory strategy for intermedia pollution control.

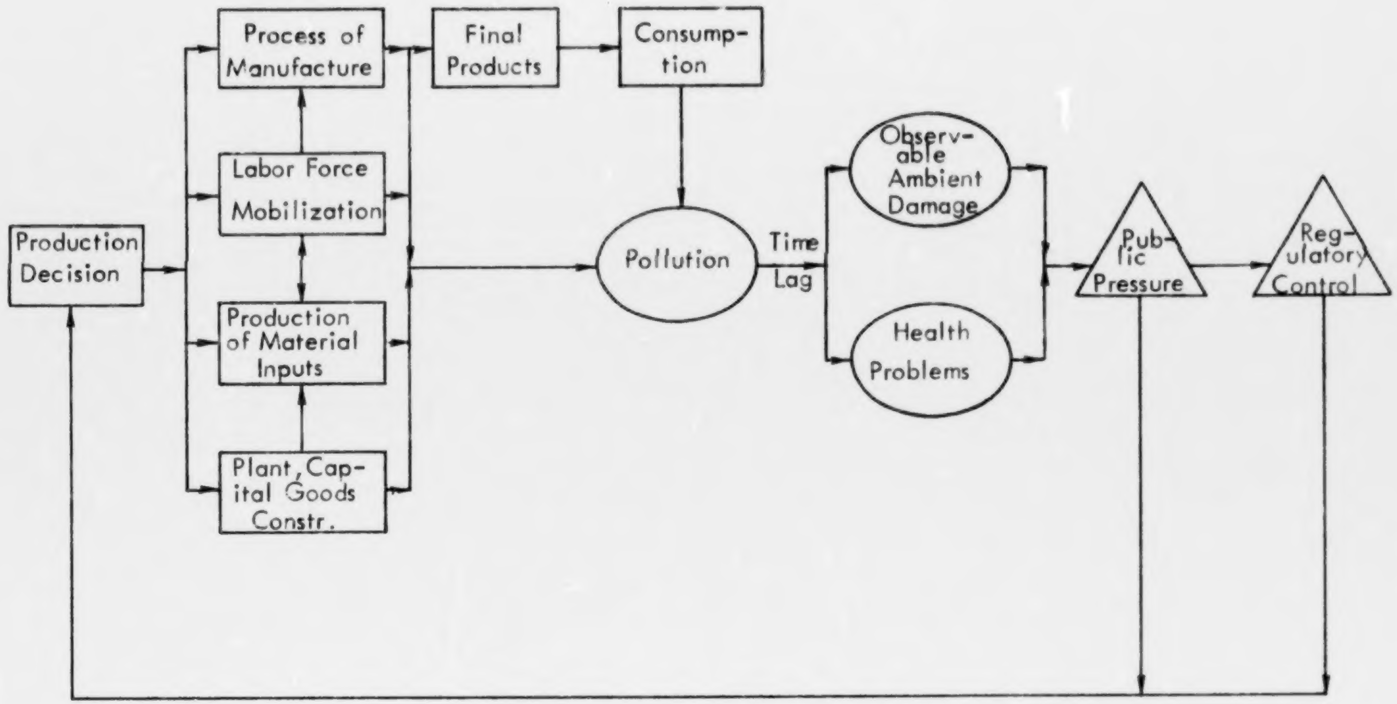

Production Decision
Process of Manufacture
Labor Force Mobilization
Production of Material Inputs
Plant, Capital Goods Constr.
Final Products
Consumption
Pollution
Time Lag
Observable Ambient Damage
Health Problems
Public Pressure
Regulatory Control

FIGURE 23
RELATED ELEMENTS IN
POLLUTION CONTROL

Some local areas are moving in the direction of integrated planning even without Federal guidelines. Inglewood, California, for example, recently established a total environmental planning process by integrating under a single director its departments of planning, redevelopment, building, housing, environmental standards, and human affairs.[345]

The Intermedia Trend

It seems clear that residues disposal tends increasingly toward the land. Control standards for air and water set either discharge limitations or ambient level tolerances. In the case of land, however, most standards and requirements influence the handling of the wastes, but do not limit the amounts disposed. That is, the air and water laws say what and how much can be discharged to the media. The land laws specify how and where it is to be handled. Thus, the California Administrative code, title 23, lists Class I, II, and III disposal sites depending upon the safeguards required for the disposal.[346] These safeguards, summarized in Table 38, mainly pertain to the prevention of landfill intermedia transfers to the air or water. While there has been discussion on the reduction of solid wastes generated by society, and the reclycling of the wastes that are generated, progress is limited. The Federal Solid Waste Disposal Act (Public Law 89-272) states as its primary purpose: "(1) To initiate and accelerate a national research and development program for new and improved methods of proper and economic solid-waste disposal, including studies directed toward the conservation of natural resources by reducing the amount of waste and unsalvageable materials and by recovery and utilization of potential resources in solid wastes and (2) to provide technical and financial assistance, to State and local governments and interstate agencies in planning, development, and conduct of solid-waste disposal programs." This act was mainly an authorization for research. The maximum appropriations authorized for 1969 were $20 million for the Department of Health, Education, and Welfare and $12.5 million for the Department of the Interior.

Although scattered local attempts have been made, no comprehensive effective program has been instituted to reduce or recycle solid wastes. Some local areas have set up incentives for the production of returnable vs. non-returnable bottles, and various independent recycling centers have been created, but these are isolated cases. Industries (plastics, glass, metal container, etc.) responsible for large amounts of solid waste have resisted, and it seems successfully, any infringement upon their ability to treat land as a free "infinite sink."

Since air and water controls are more stringent than those on land, the residues resulting from these controls are frequently deposited on the land. This is not always the case, however. In Los Angeles, most industrial wastes are discharged to the sewer system. The treated water, from the 420 mgd hyperion treatment plant, is discharged to the ocean five miles offshore and the sludge generated is discharged seven miles offshore.[302] The City is under an order, however, from the State of California and the EPA to find an alternate disposal method. This problem is further discussed in Section IX, the Regional Case Study.

TABLE 38

CALIFORNIA LANDFILL SITE STANDARDS[302]

Class	Land Criteria	Materials Allowed
I	Sites located on formations through which no appreciable seepage to usable waters can occur, or underlain by isolated bodies of unusable groundwater and which are protected from surface runoff and where surface drainage can be restricted to the site or discharged safely.	No limitations.
II	Sites underlain by usable groundwater where the minimum elevation of the dump can be maintained above the record and/or anticipated high groundwater elevation or where sufficient protection can be provided to prevent significant amounts of usable groundwater from flowing through the waste material deposited, and where surface drainage can be restricted to the site or discharged to a suitable waste way.	Limited to ordinary household and commercial refuse, garbage, other decomposable organic refuse, scrap metal and material described under Class III sites.
III	Sites located so as to afford little or no protection to usable waters of the State.	Limited to inert solid materials and such other solids or liquids as may be listed in State Water Resources Control Board requirements for the specific site.

SECTION VIII
THE MATHEMATICAL MODEL
INTRODUCTION

The development of a model which aids the evaluation and analysis of intermedia pollution problems is a very complex task. Many factors are involved and the problem of incomplete and missing information is a serious handicap.

A Materials' Balance Approach

Kneese, Ayres and d'Arge have presented a very comprehensive theoretical analysis of pollution problems and the economic system using a materials' balance approach.[329] This approach requires a complete accounting of all physical flows in the economy. The authors use the following array of variables:

Array	Dimensions	Description
r	(M x 1)	Resources and services (physical)
v	(M x 1)	Resource and service prices
x	(N x 1)	Products or commodities (physical)
p	(N x 1)	Product or commodity prices
y	(N x 1)	Final demands (physical)

The i^{th} resource r_i is allocated among the N sectors so that $r_i = \sum_{k=1}^{N} a_{ik} X_r$, $i = 1, 2 -- M$.

The total allocation of resources among activities in the economy can then be represented in matrix form in the following manner:

$$\begin{bmatrix} r_1 \\ \vdots \\ \vdots \\ r_M \end{bmatrix} = \begin{bmatrix} a_{11} & --- & a_{1N} \\ a_{21} & a_{22} - & a_{2N} \\ & & \\ a_{M1} & --- & a_{MN} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ \vdots \\ \vdots \\ X_N \end{bmatrix} \qquad (1)$$

A similar set of equations describes the relations between commodity production and final demand:

$$\begin{bmatrix} X_1 \\ \vdots \\ X_N \end{bmatrix} = \begin{bmatrix} A_{11} & --- & A_{1N} \\ \vdots & & \vdots \\ A_{N1} & --- & A_{NN} \end{bmatrix} \cdot \begin{bmatrix} Y_1 \\ \vdots \\ Y_N \end{bmatrix} \qquad (2)$$

Where $[A]$ is given by: $[A] = [I - C]^{-1}$ and where I is the unit diagonal matrix and the elements C_{ij}, of the matrix C are are essentially the well-known Leontief input coefficients.

The authors then combine (1) and (2):

$$\begin{bmatrix} r_1 \\ \vdots \\ r_M \end{bmatrix} = \begin{bmatrix} a_{11} & - - - & a_{1M} \\ \vdots & & \vdots \\ A_{N1} & - - - & A_{NM} \end{bmatrix} \begin{bmatrix} A_{11} & - - - & A_{1N} \\ \vdots & & \vdots \\ A_{N1} & - - - & A_{MN} \end{bmatrix} \begin{bmatrix} Y_1 \\ \vdots \\ Y_N \end{bmatrix}$$

$$\begin{bmatrix} G_{11} & - - - & G_{1N} \\ \vdots & & \vdots \\ G_{MN} & - - - & G_{MN} \end{bmatrix} \begin{bmatrix} Y_1 \\ \vdots \\ Y_N \end{bmatrix} \qquad (3)$$

and the equilibrium price vector, p:

$$(p_1 - - p_M) = (V_1 - - V_M) \begin{bmatrix} G_{11} & - - & G_{1N} \\ \vdots & & \vdots \\ G_{M1} & - - & G_{MN} \end{bmatrix} \qquad (4)$$

To complete the model in a materials balance form it was necessary for the authors to close the system so that there would no net gain or loss of physical substances. To do this, two additional sectors, X_θ, the environmental sector,and X_f, the final consumpt sector,were introduced. This modification is shown in detail in their paper.[329] The equations relating material flows were then expressed and these flows to and from the fi sector balanced:[329]

$$\sum_{k=1}^{N} C_{kf} X_f = \sum_{k=1}^{N} C_{fk} \; C_{fk} X_{k7} + C_{f\theta} X_\theta \qquad (5)$$

Sum of all final goods	Sum of all materials recycled	Waste residuals plus stock and capital accumulation

where:

$$X_f = \sum_{i=1}^{N} Y_i$$ is the sum of all final demands.

Materials flows into and out of the intermediate product sector must also balance.

$$\sum_{j=1}^{L} \sum_{k=1}^{N} G_{jk}^{M} - \sum_{j=1}^{N} Y_j + \gamma \sum_{j=1}^{N} \sum_{k=1}^{N} C_{fj} \; A_{jk} \; Y_k = \sum_{k=1}^{N} C_{k\theta} X\theta \qquad (6)$$

All production not including services	Final demand	Recycled products	Residues to environment

The coefficient γ represents the proportion of recycled materials from the final sector, f, which augments material resources in the intermediate products sector. Total residue flows to the environment can then be represented as residue flows from final consumption (from equation 5) and from intermediate products (from equation 6):

$$C_{t\theta} X_{\theta} = \sum_{k=1}^{N} C_{k\theta} X_{\theta} + C_{f\theta} X_{\theta}$$

A final mass balance relationship is then developed which states "materials flows from the environment less continuously recycled products equals residual flows from the intermediate products sector plus residual flows resulting from final consumption."[329] The authors then apply this framework to the inclusion of externalities (such as environmental and social costs) not reflected in the supply functions of the Walras-Cassel system. Several alternative methods of incorporating these social costs into the market structure to derive a Pareto optimum are then discussed.[329] The authors present a very enlightening discussion of the shortcomings of economic theory and of methods for evaluating intermedia problems. However, current information constraints make it impossible to apply this method in its entirety to intermedia problems in the near future. The authors recommend future research on the variables in their model and recognize that work for the immediate future will have to proceed with more modest data requirements. Four areas of difficulty are encountered in applying this model as developed. First, complete information is not now available for all material flows in the economy; only dollar flows are available on a comprehensive basis. Second, consumer utility functions are not well known; the slope and position of these utility functions must be determined since the solution to environmental problems involves changing costs and prices. Third, a system in equilibrium is assumed which is almost never encountered, since the role of unemployment is ignored. Finally, changes in the technological coefficients (a_{ij} and A_{ij} in the model)and capital investment are an inherent part of this intermedia study. This means the factor demand curves for industries must also be known.

To overcome these difficulties this section will present a model organized along slightly different lines which is cognizant of the restrictions placed on analysis by information constraints.

The Water, Air and Residues Model (WARM)

Input-output tables relating known flows in dollars between productive sectors and for final consumption will be used along with currently available information for the identified major pollutants. Because of the lack of available information, the model will be environmentally "open" as opposed to the "closed" materials balances model presented above. The data will then be evaluated on an incremental basis by forecasting the change in material flows and pollutant residues which are created by different pollution control programs. Complete information concerning material flow patterns will not then be needed. Constraints on material supplies will keep the model within reasonable bounds. The shifts in the composition of the output of the economies caused by cost changes and their impact on demand will not be quantitatively evaluated in WARM. A desired output composition will be assumed for the economy and alternative methods for achieving this output, subject to constraints on pollutant emissions, will be evaluated generally in terms of costs and pollutants although these variables can be inputs to the model to obtain other outputs.

The analytical approach must consider all sectors of the economy that have a significant impact upon environmental quality. The two digit level of the Standard Industrial Classification (SIC) codes will be used except for the analysis of certain highly significant sectors on a four digit SIC code basis.

At the core of the mathematical model is a matrix expressing production and pollution control interactions, using a fixed final demand. The latter is determined by forces outside the model. The model can estimate the effects of discharge controls on production and prices, the intermedia effects of different control processes, and total costs for strategy implementation.

Where pollutants are products of final consumption (which has no sector designation), output from the most closely related retail sector must be used to incorporate the pollutant output into the model. An example is the sale of gasoline rather than automobile-miles as a measure of pollutants from gasoline consumption. Recycling of waste materials can be accounted for by modifying the inter industry trading patterns which form the input-output portion of the model.

The model constraints on pollutant discharges will be derived from the ambient standards for the environment set by the Environmental Protection Agency, or local/State governments. In order to derive the discharge constraints from the ambient standards, a basic understanding of the dynamic response of the environment is needed. There are many different approaches and levels of sophistication from which to approach this problem. They will be briefly discussed in the section on Ambient Levels and Discharge Rates.

For the present, it will be assumed that limitations on discharges expressed by time place, and pollutant can be derived from the established ambient standards, independently of WARM, and used as the models' constraints.

Either a linear programming (optimization) or a simulation approach could be used in solving this model. Considering the emission or discharge standards as model constraints, the other objectives such as control cost, manpower, etc. must be mathematically expressible and related to use the linear programming approach. If these objectives cannot be so expressed or quantified, a simulation or trial and error approach can be used to determine the optimum result. The linear programming approach would internally arrive at the best possible solution state given the constraints and the objectives used. Since the regional data available do not permit a meaningful mathematical expression of these objectives, the simulation approach will be used for this regional study. In this approach alternative solutions would be chosen outside the model, which will then predict the effect of these solutions on industrial production, pollutant discharges, prices, etc.

To make the model more flexible the pollution control processes will be included in the productive activity portion of it, rather than expressing them as separate activities. This will be explained further in the section "Pollution Control and the Productive Activities."

Due to the localized characteristics of ambient air and water basins, and of the economy, and the pollution control administrative functions, the mathematical model will be developed as a regional model. The structure will permit generalizing for use on a national level, but the result may be so generalized as not to be relevant to any particular area.

MATHEMATICAL MODEL REPRESENTATION

Input-Output Data

The first step will be to start with the data in the National input-output (I/0) tables which are available, updated to 1966 from 1963.[296] The following expressions define the basic elements of the model. Expressions in parentheses indicate vector dimensions.

C^{o} (1 x m) = value added by production vector in 1966 I/0 tables

A^{o}_{11} = 1966 I/0 table coefficients

The next step is to modify these data based on knowledge of the special conditions in the region to be studied.

$A_{11} = A^{o}_{11}$ + modifications

$C^{1} = C^{o}$ + modifications

Now, the regional output vector must be calculated where no available information exists. The regional labor productivity will be assumed equal to the national labor productivity for each industrial sector.

If contrary information exists, a constant, D, will be used to convert the ratios.

Since: $$\frac{X_i}{L_i} = D\,\frac{X_i^{N}}{L_i^{N}}$$

Then: $$X_i = \frac{D\,X_i^{N}\,L_i}{L_i^{N}}$$

Where: X_i = Production in dollars of sector (i) for the region

X_i^{N} = National production in dollars for sector (i)

L_i^{N} = Labor expended in sector (i) nationally

L_i = Labor expended in sector (i) in the region

N = National data

Labor is expressed as the number of full-time employee equivalents employed in this sector. The next step is to calculate the inputs required by industry to produce the output calculated above.

$$R_i = \sum_{j=1}^{N} X_j a_{ij} \qquad i = 1, 2, ---, M$$

Where: R_i = Regional inputs required for production in sector (i).

a_{ij} = Regional I/0 matrix coefficients.

Now, the net output (production less required inputs) can be calculated:

$$b_i^1 = X_i - R_i \qquad i = 1, 2, ---, M$$

Where: b_i^1 = Net production over needs in region.

Also: $b_i^1 = Y_i + W_i$

Where: Y_i = Final demand in region for sector (i).

W_i = Net trade (exports-imports) for good (i)

Available input-output data are on a National level. These data must be modified by local conditions, local output, and interregional trading patterns. Physical output is obtainable on a regional level since the number of employees by SIC sector is available and can be used as an index to production. The resulting figures represent the gross output from each sector in the region. In order to estimate final deliveries available for consumption, it is necessary to estimate the part of gross outputs that is used in the production processes. This amount must be subtracted from gross output to derive final deliveries available for consumption. It should be understood that this amount available for consumption then includes interregional trade and final demand. In order to separate regional consumption from interregional trade, independent data must be gathered for these two components. All areas outside of the region will then be treated in the same manner as are imports and exports in the National economy.

Appendix Tables I and II are examples of the kind of input-output information needed for analysis by the mathematical model. Table I describes expenditures, at the two-digit SIC Code level updated to the year 1971. Table II describes the production units and quantities for the same industries also updated to 1971.

Consideration of Pollution and Control Strategy Data

Based on research during this project, the following information will be provided:

Matrix	Dimension	Description
A_{12}	$[M_1 \times (N-M1_1)]$	Alternative activity matrix.
A_{21}	$(M_2 \times M_1)$	Supply constraint coeffecients of critical materials and labor.
A_{22}	$[M_2 \times (N-M_1)]$	
A_{31}	$(M_3 \times M_1)$	Pollutant output matrix for activities.
A_{32}	$[M_3 \times (N-M_1)]$	
A_{41}	$M_4 \times M_1)$	Pollutant output matrix for special area problems
A_{42}	$[M_4 \times (N-M_1)]$	
A_{51}	$(M_5 \times M_1)$	Pollutant output matrix for special time peaks.
A_{52}	$[M_5 \times (N-M_1)]$	
b^2	$(M_2 \times 1)$	Constraints on supply of materials and labor.
b^3	$[(M_3 \times 1)]$	Constraints on total pollutant output.
b^4	$(M_4 \times 1)$	Special area constraints.
b^5	$(M_5 \times 1)$	Special time constraints.
C^2	$[1 \times (N-M_1)]$	Alternative process cost vector.

N = Number of columns (activities) in the matrix.

M = Number of rows (coefficients of production and pollution) in the matrix.

Model Solution Process

Linear Programming Approach This approach assumes the capability to develop a meaningful objective function. It also assumes sufficient confidence in the constraint and matrix coefficients to find the optimum solution mathematically.

Solve: Minimum $Z = C^1 X^1 + C^2 X^2$

Subject to:

$$\begin{bmatrix} A_{11} & \vdots & A_{12} \\ A_{21} & \vdots & A_{22} \\ A_{31} & \vdots & A_{32} \\ A_{41} & \vdots & A_{42} \\ A_{51} & \vdots & A_{52} \end{bmatrix} \begin{bmatrix} \\ X^1 \\ \\ X^2 \\ \\ \end{bmatrix} \begin{matrix} \geq \\ \leq \\ \leq \\ \leq \\ \leq \end{matrix} \begin{bmatrix} b^1 \\ b^2 \\ b^3 \\ b^4 \\ b^5 \end{bmatrix}$$

$(M \times N)$ $(N \times 1)$ $(m \times 1)$

Where: $M = M_1 + M_2 + M_3 + M_4 : M_5$

X^1 is of dimension $(M_1 \times 1)$

X^2 is of dimension $[(N-M_1) \times 1]$

In order to solve a system of inequalities, slack variables must be used to convert to equalities. The final equation system then becomes:

$$X \text{ Min } Z = C^1 X^1 + C^2 X^2$$

Subject to:

$$\begin{bmatrix} A_{11} & \vdots & A_{12} & -S^1 \\ A_{21} & \vdots & A_{22} & +S^2 \\ A_{31} & \vdots & A_{32} & +S^3 \\ A_{41} & \vdots & A_{42} & +S4 \\ A_{51} & \vdots & A_{52} & +S^5 \end{bmatrix} \begin{bmatrix} \\ X^1 \\ \\ X^2 \\ \\ \end{bmatrix} = \begin{bmatrix} b^1 \\ b^2 \\ b^3 \\ b^4 \\ b^5 \end{bmatrix}$$

$[M \times (N + M)]$

Where: S^1, S^2, S^3, S^4, and S^5 are slack variable matrices with a total of M columns.

This approach assumes the capability to develop a meaningful objective function. It also assumes sufficient confidence in the constraint and matrix coefficients to find the optimum solution mathematically.

Simulation Approach If the data will not yield a meaningful objective function, or if significant non-quantifiable parameters are involved, a trial and error approach may be the best. This approach presents an array of solutions from which a choice can be made based on considerations other than just those quantified in the model.

The first step is to select a set of vectors from the model (implying a choice of pollution control strategies). This choice would involve only the first M_1 equations and would involve M_1 activities. If B_{11} is a subset of A_{11}, A_{12} of dimension $(M_1 \times M_1)$ then $\hat{X} = B_{11}^{-1} b^1$ yields the total output by sector. This result would then be multiplied through the rest of the matrix in order to forecast the effect on supplies required and on pollution produced by all included sectors.

$$b^2 = B_{21} \hat{X}$$

$$b^3 = B_{31} \hat{X}$$

$$b^4 = B_{41} \hat{X}$$

$$b^5 = B_{51} \hat{X}$$

It should be pointed out that there is no guarantee with this method that the solution will be feasible. That is, negative production and excessive pollution are not precluded. The analysis must proceed in a trial and error fashion to find feasible solutions. Only the linear programming approach forces the model to stay feasible at all times.

Information Needed on Control Alternatives

Technical Information The following information will be necessary to develop properly the technical coefficients in the model.

(1) Pollutant removal efficiencies by process and industry and the effects of treatment combinations.

(2) Residues or alternative pollutants created by the control processes - i.e. intermedia effects.

(3) State of discharges before treatment.

(4) Materials consumed in the control processes.

(5) Effects of controls on industrial production, efficiencies, and trading patterns.
(6) Residue recycling possibilities.
(7) Supply constraints on critical materials.
(8) Pollution created by consumption of the products.
(9) Pollutant sources in critical geographical areas within the region.
(10) Pollutant sources which cause problems at particular times of the day and the locations and times of these problems within the region.

The United States Department of the Interior has published in Geological Survey Circular 645 a proposed matrix approach for Environmental Impact Statements.[360] This matrix details all the types of activities involved in a new project and their impact on the region's environment. This information, if required, would be a big aid to environmental planning and would provide much needed information for WARM. Still, the matrix could be more comprehensive. A list of the materials required for construction and for yearly operation even if to be provided from outside the region would be important. This would provide more information to national planners on physical intersectoral input-output relationships and also on relationships between regions. Unless this is included, the Environmental Impact Statements will not be complete.

Cost Information The following cost information will be necessary for the controls included in the model.

(1) Capital investment required.
(2) Estimate of period of investment or life of facilities.
(3) The applicable interest rate.
(4) Operating costs.
(5) Capital and operating costs for residue disposal. These include costs of

    a) Vehicles necessary
    b) Labor for hauling
    c) Dumping
    d) Recycling, if any

(6) Sale value of the residue or recycled products.

Cost Derivation Formula The costs below will not include the cost of materials represented in the vector as coming from other sectors, since costs from external sectors are included in the originating sector.[271]

Given:

Capital Investment Required	I
Life of Investment	n
Interest Rate	i
Operating Cost	V
Value of Residues	S

The capital recovery factor,[271]

$$R = \frac{i\,(1 + i)^n}{(1 + i)^n - 1} = \frac{1}{PV_a} \qquad (2)$$

Where PV_a is the present value of an annuity (a) for n years at interest rate i, R is the cost of the capital investment and the year-end payment per $1 invested that will recover the cost of the project in n years at interest rate, i.

The total cost $T_i = R_n^i \; I_i + V_i - S_i$ (3)

Sample Values for R_n^i

n	i = 5%	i = 8%	i = 10%
10	0.12950	0.14903	0.16275
20	0.08024	0.10185	0.11746
30	0.06505	0.08883	0.10608
40	0.05828	0.08386	0.10226

The new cost of an alternative activity vector is $C_i + k$. Where values are given for:

C_i = Value added in I/0 table.

I_i = Calculated additional cost of this control process.

k-1 = Number of activities occurring in the matrix between the original activity and the alternative.

$$C_{i+k} = C_i + T_i \quad \text{for } i = 1, 2, \ldots, N \qquad (4)$$

Ambient Levels and Discharge Rates

The determination of ambient pollution levels from discharge rates can be approached in several ways. Zimmer and Larsen, in an article in the Journal of the Air Pollution Control Association, presented one approach.[269] They accounted for peaks in ambient levels by using varying lengths of time over which concentrations were averaged. The shorter the time period the more accurate were the averages with respect to peaks. They made one simplifying assumption. They assumed that ambient air levels would respond to changes in discharge rates in a direct 1:1 ratio. That is, a reduction of K percent in discharges would reduce ambient levels by K percent. In many cases, this relationship is tenuous at best. For example, in the case of chlorinated hydrocarbons such as DDT, the intermedia transfer from air to water or land will remain long after the use of DDT is halted.

Russell and Spofford have discussed the use of non-linear ambient "transfer functions" expressed for particular areas as useful guides to the relationship between discharges and ambient levels.[270] The relationships are very complicated and difficult to quantify using the type of data that is available.

The approach to be used in this report has not yet been finalized, however, some basic formulations have been made.

At the regional level, it is not sufficient to look at gross pollutant discharges as the sole parameter. Factory hours and physical distributions, time peaks, and small area pollutant concentrations cannot be ignored. Since only a few of these problems still exist, it is not necessary to use time and area grids covering the entire region. These would unduly increase the size of the matrix to no great benefit. Instead, certain time periods in selected areas will be evaluated in addition to gross regional discharges. The selected areas will be those areas where maximum pollutant peaks occur consistently. The mathematics for doing this were presented in the section in this chapter entitled "Mathematical Model Representation." With regard to ambient levels, a linear relationship will tentatively be used and modified in certain instances.

Pollution Control and the Productive Activities

Leontief had suggested that his input/output analysis could be used as a guide to pollution problems by augmenting his input/output matrix with pollution control vectors as separate economic activities.[267] This would raise certain practical and theoretical problems.

To use Leontief's approach, at least one row for each pollutant must be added to the model. A pollution control sector must then be created for each pollutant. Leontief's augmented matrix in partitioned form is presented below.

$$\left[\begin{array}{c|c} I - A_{11} & -A_{12} \\ \hline A_{21} & -I + A_{22} \end{array}\right] \left[\begin{array}{c} X^1 \\ \hline X^2 \end{array}\right] = \left[\begin{array}{c} Y^1 \\ \hline Y^2 \end{array}\right]$$

Where:

$I-A_{11}$ = The production input/output matrix.
A_{12} = The products used by the control processes.
A_{21} = Pollutants produced per unit of product produced by $I-A_{11}$.
A'_{22} = Pollutants eliminated (or produced) by the control processes.
X^1 = Product output vector.
X^2 = Pollutant elimination vector.
Y^1 = Production for final consumption.
Y^2 = Final demand for pollutant elimination.

if this sytem is solved, a strategy is input and estimated costs and prices emanating from an initial demand for the elimination of pollutants is derived. This approach entails serious problems as discussed below.

Size

At first glance, only one control activity is necessary per pollutant in the matrix plus one row added per pollutant to be controlled. However, the control strategies and costs vary by industry. Each process may affect a combination of pollutants. Its efficiency may also depend upon previous treatment methods employed. A realistic approach would require many different control sectors categorized by industry and would result in a phenomenal increasee in matrix size.

Non-Linearities

The pollution control relationships are not linear; for example, if a plant puts in an electrostatic precipitator and removes 70 percent of the particulates from its emissions, then doubling the level of control cannot double the amount of particulates removed. Therefore, constraints on the ratio between the productive activity and the control activity are necessary. This type constraint cannot be directly expressed in an input/output matrix problem.

Conclusion

Because of the problems outlined above, pollution controls are treated in this study as part of the individual productive processes. In this way, the problems noted above can be resolved. In order to do this, the effects of a cortrol strategy for a particular industry on the input/output vector can be determined. The modified vector is then entered as an alternative vector in the matrix. A different alternative vector for each strategy to be considered is required. Evey possible strategy will not be evaluated. Only the ones considered promising will be incorporated into the model.

The Model Aggregational Level

Aggregation Process Since most of the model data will be presented on a two-digit SIC code level, the aggregation process must be specified. Much of the data is on a per-unit basis such as pounds of pollutant per ton of product. These data are for specific industries, not the SIC level used in the model. Since ratios cannot be added, the first step is to convert these ratios to total pollutants produced by sector by multiplying by the amounts of products produced. These figures can then be added in order to aggregate them into the model SIC categories. The total pollutant SIC sector will then be divided by the dollar output for that sector to calculate pollutant per dollar output. This will be done for all sectors and all pollutants.

The equations are presented below.

$$a_{ij} = \frac{\sum_{k=1}^{K} P_{ijk} \quad Q_{ijk}}{b^{i}} \qquad \begin{array}{l} i = 1, 2, ---, M \\ j = 1, 2, ---, N \end{array}$$

Where: a_{ij} = Pollutant (i) per dollar output in model SIC sector (i).

P_{ijk} = Pollutant (i) per unit of output of product (k) in model SIC sector (j)

Q_{jk} = Production of product (k) in model SIC sector (j).

b_{i} = Dollar output in model SIC sector (i).

Developing the Aggregational Level There are many two-digit sectors which do not contribute significantly to the pollution problem and which can be aggregated into one single sector. On the other hand, sectors like SIC 28 which contain several very significant pollution sources are only poorly analyzed on a two-digit SIC level. Sector 28, for example, contains 2812 alkalies and chlorine, 2871-74 fertilizer production, 2845 carbon black production, and 2899 charcoal manufacture, all distinctly different and very significant sources of pollutant. The model will provide better information with no increase in matrix size by grouping two-digit sectors which individually contribute insignificant ambients of pollution, and using a three or four-digit SIC level for certain highly significant sectors (like sector 28).

SECTION IX

REGIONAL STUDY

GENERAL CONSIDERATIONS

The purpose of the regional study is to apply,on a smaller and more manageable scale, the principles and ideas which have been generated by the study as a whole. The policies and strategies for control vary greatly from state to state and from locality to locality. This has allowed "shopping around" for areas of less stringent standards when choosing a plant location. These variable standards also make it impossible to generalize about the desirability of transferring a given pollutant from one medium to another. In one area, conditions might be such that to remove a pollutant from the air and place it in the water might be the best possible choice, while in another area that same pollutant might better be left in the air. Such choices can only be made on a regional basis. If national standards were to be adopted, the present conditions in different areas would require different strategies to maintain the standards, and within a given region, the costs versus the effects of intermedia transfer may be different from those in another region. It might be that the cost of transferring a pollutant is too high to justify, or the transfer might be of insufficient benefit to justify the cost. This is the purpose of the regional study; it shows how these determinations might be made and which considerations go into making them.

Criteria for Selection of the Region

When selecting the region to be used for this study, variety and availability of information were the key criteria. A region was sought having a variety of activities and environments. For example, the region should have several types of water; ocean water, fresh surface water, and ground water, for each has different pollution problems. Ground water has the possibility of contamination due to leaching from landfills or from sea water intrusion, ocean water and fresh water react differently to various pollutants because of their differing salt content. The industrial activities of the region should include a variety of processes and products in order that as many kinds of pollutants and control methods are represented as possible. The region should have an urban population,as most pollution sources are associated with urban areas,but it should include rural and agricultural areas to be representative. The region should be easily defined geographically, with natural boundaries such as mountains or the ocean, rather than political boundaries. This insures that pollution created within the region will largely remain there and that the pollution found within the region was mostly created there.

Description of the Region

With these controlling criteria, the Los Angeles Metropolitan Area was selected as the region for study. This region includes Ventura and Orange Counties in their entirety and portions of Los Angeles, San Bernardino, and Riverside Counties. It is bounded on the north and east by the San Gabriel, San Bernardino, San Gorgonio, San Jacinto, and Santa Ynez Mountains and on the south and west by the Pacific Ocean and the San Diego County line. This region coincides almost exactly with the South Coast Air Basin of the California Air Resources Board (disregarding the Santa Barbara County portion)[299] and the combined Los Angeles and Santa Ana Regional Boards of the State

Water Quality Control Board.[303,304] These Regional Boards include the Santa Clara, Los Angeles and Santa Ana River Basins. These rivers all have their sources in the mountains in the northern and eastern portion of the region and flow to the ocean. The criteria for the study region are thus met, as there are three types of water, all susceptible to pollution; a wide range of industries to provide the variety of air, land and water pollutants and controls; a large urban population with a surrounding suburban population; and a very significant agricultural area in San Bernardino, Riverside, and Orange Counties. The region is largely isolated by mountains and the ocean to minimize the transfer of pollutants across its boundaries.

The Los Angeles Metropolitan Region is located on a coastal plain and in contiguous valleys and extends inward from the coast for fifty to seventy-five miles. Nearly ten million people, almost half the population of the state, live in the region.[299] This population is not evenly distributed within the region. In the included portion of Los Angeles County there are 2500 people per square mile, while in the Riverside County portion the population density is 173 people per square mile.[299] This does not represent the extremes in population density, for downtown Los Angeles has nearly 16,000 people per square mile[300] while in some of the mountain and wilderness areas the density drops nearly to zero. The region includes about 64,000 square miles or 6 percent of the total land area of the state.[299]

History of the Region, Pre-World War II

The Los Angeles Metropolitan Area of today bears little resemblance to its appearance in the late 1930's. At that time the region was mainly agricultural, with citrus predominant and a scattering of walnut orchards. The major non-agricultural industries were tourism, the motion pictures and aviation.[312] It did not have the large urban population and the complex of interlocked communities of today, but instead there were many small agricultural towns connected by small highways to the larger cities. The railroad was the major method of transportation and electric trains connected the individual towns.[312] Each city had its own sewage treatment facility and the pollution problems were quite different from those of today. There were no complex pesticides in use, but the farmers did use boron and arsenic to control pests. Boron found its way into the ground waters and caused the loss of citrus trees. The effluent from treatment plants was discharged to dry streams and river beds where, through percolation, it contaminated the ground water. Historically, the cities within the region which had their own wells and sewage systems were able to remain independent while those lacking these basic facilities were often forced to join with cities having them (Los Angeles in particular).[311] At this time some regional sewage treatment was being done by the Los Angeles County Sanitation Districts, but this was only for unincorporated areas rather than for the various cities. The Metropolitan Water District was formed by the City of Los Angeles and other communities to import Colorado River water and more recently (1972) from Northern California.

Even though the region is semi-arid, flooding is a significant hazard during rainy periods. The Flood Control District was founded in order to deal with this problem. In the early years, the District merely kept people from the flood plains. In later years, flood control dams, basins and channels were constructed to collect flood waters, channel them through the region, and still later to utilize the drainage for ground water recharging.

All types of industry were encouraged to locate in the region. As these industries came in, they centered in county areas because regulations were less strict than in many cities. There was increased need for improved roads and new sewage treatment plants; there were more jobs for more people resulting in more money and more growth for the region. On the whole, industrial wealth was of more concern than plant effluent quality and most monitoring of effluent was for detection of health hazards such as bacteria or toxic wastes and their effect on receiving waters. The sewage sludge from various plants was reclaimed and used for soil conditioner or fertilizer in the extensive local agricultural areas.

During this time air pollution was a minor problem. Open burning was allowed in dumps, and stationary sources, not automobiles, were the largest emitters.[301] The smudge pots used in the citrus orchards as protection against frost were a major source. About the only air pollution problem which people were concerned with was a decrease in visibility.[301]

History of the Region - Post World War II

After World War II the situation in the region changed rapidly with a marked population increase and industrial expansion. Chemicals (insecticides and plastics) and paper were among the first industries to join the postwar boom in the region. As the population increased, freeways replaced the electric railroad for public transportation and airplanes and trucks replaced the railroad for transportation of goods and merchandise. Houses replaced agricultural areas and beaches became highly developed.[312]

As population increased and the region became more industrialized, more water was required since industry demands more water than do agriculture and domestic use. As the demand increased, more water importation became necessary. The region has undertaken three of these projects, one from the Colorado River and two from the Sierra Nevada mountains. With this imported water the local cities were able to expand even more.[311]

Environmental control has evolved from a strictly local concern to a regional need. The pattern of every city having its own sewage treatment plant has given way to a pattern of fewer, larger regional plants, especially in Los Angeles County. The setting of standards and the control of emissions is now on a regional basis. Previously, water quality standards were set by the health department; now they are set by the State Wa Resources Control Board through the two Regional Water Quality Control Boards in the area. A similar situation exists for air. The various Air Pollution Control Districts, which are sub-regional bodies, have been responsible for air quality within the region. The Air Resources Board, a State agency, now has control and administers the entire region as a unit.[299] All local, City and County agencies now operate through these regional boards to the State level, while the Federal controls are administered through the States, making it the major enforcer of environmental protection laws. The State Legislature conducts hearings on environmental problems, and both the Attorney General and the Grand Jury have the right and power to conduct investigations.[299]

In the last five years there has been a change in priorities by the general public and now there is more concern expressed for the environment and less emphasis shown on growth. Most communities seem to prefer light industries requiring limited water use to heavy industry employing wet processes. The desire apparently is to minimize the environmental impact of industry on the community. The emphasis on public health through environmental protection is superseding that on industrial and individual safety.

More and more frequently people are questioning if the damage caused by "progress" is worth the gain. Beginning in 1972 a policy was initiated which calls for an environmental impact statement to be written before any new construction can be started.[300]

The protection of the environment has become an important political issue and a number of organizations are actively involved in lobbying for environmental legislation. These organizations include such groups as the Sierra Club, Friends of the Santa Monica Mountains' Parks, and other professional, civic and special interest groups. The trend in legislation is toward more public control. The situation has gone from one of no control to control by the pollution sources, and now is progressing toward one of public control.

New legislation has meant stronger laws, higher standards and greater enforcements. A polluter may now be liable for up to $6,000 per day in fines. Discharge standards have been strengthened or created for such things as heavy metals and toxic materials and monitoring has become more extensive. A potential water pollution source is now required to submit a report of discharge. If this discharge is made directly to receiving waters, the discharge must meet state standards;[302,303] if the discharge is to a sewer system the standards for the discharger are lower but he must usually pay in proportion to the amount of various pollutants in the discharge.[304] industrial discharges previously were at least partially obscured by emptying into municipal systems, but new legislation has made this more difficult by requiring the industries to have a permit, often for each connection. To obtain these permits, industries must report the quantity of discharge and the specific chemical makeup of each discharge. Nor is it only industry that is having to change, for the two largest sewage treatment plants which have for a long time deposited some or all of their sludge in the ocean have been ordered to stop the practice and find an alternate disposal method.[302]

Methods for measuring degradation have also changed. Wastewater monitoring has changed from measuring the effect on receiving waters to measuring also the quality of the discharge. Toxic effects of the various air pollutants has replaced visibility as the major criteria for determining the severity of an air pollution problem.[301]

The pollution problems in the Los Angeles Metropolitan Region are severe, especially the air pollution problem. However, the State and the local agencies charged with the responsibility for solving these problems are confident that solutions are possible and, indeed, are already underway.[1,3,4,5] In the remainder of this regional study, the extent of the role of intermedia transfer in these solutions will be examined.

INSTITUTIONAL FACTORS

In the State of California, the agency charged with the major portion of environmental affairs is the State Resources Agency. Operating within this agency are the Air Resources Board,[299] the Water Quality Control Board,[302,303] and the newly formed Solid Waste Management Board.[313] The State may also act on environmental matters through the counties, cities and other local and regional governments and districts. These interrelationships are shown in Figure 24 .

Air Pollution Institutional Factor

The Air Resources Board has the major responsibility for protecting the air quality of the region. The State contains eleven air basins; the one coinciding with the Los Angeles Metropolitan Region is the South Coast Air Basin.[299] The relation of the Air Resources Board to other agencies within the region is shown in Figure 25 , which also indicates that each county has an Air Pollution Control District. It is through these districts that the Air Resources Board works. Control of stationary sources of air pollution is within the jurisdiction of the local Air Pollution Control Districts, while mobile sources are controlled by the State.[299] Aside from being responsible to the Air Resources Board, each Air Pollution Control District is responsible to its County.[301] Several of the southern counties and many of the cities within them have voluntarily joined to form the Southern California Association of Governments (SCAG). While this body has no authority of its own, it is recognized as the environmental planning agency in the region.[300]

Water Pollution Institutional Factors

Figure 26 illustrates that a number of agencies have authority in the control of water pollution. Primary responsibility for water quality within the region lies with the two Regional Boards of the Water Quality Control Boards.[302,303] They are charged with coordinating the water quality efforts of all other agencies. Most cities take responsibility for the quality of water supplies within their boundaries, but many deliver waste water to the county for treatment. Each county has several agencies involved partly or entirely in water management. These include County Sanitation Districts, County Flood Control Districts, County Board of Health, County Engineer, and others. As with air pollution, SCAG is involved in overall regional planning.[300]

Land Pollution Institutional Factors

The Solid Waste Management Board is the newly created agency to assist in controlling pollution.[313] Before its creation each county and city set their own standards and practices for the disposal of solid wastes, although the Water Quality Control Board has set standards concerning placement of landfills for the protection of ground water supplies.[302,303] The new Board is required to set standards for solid waste disposal by January 1, 1975.[313] Present interactions among various agencies may be seen in Figure 27 .

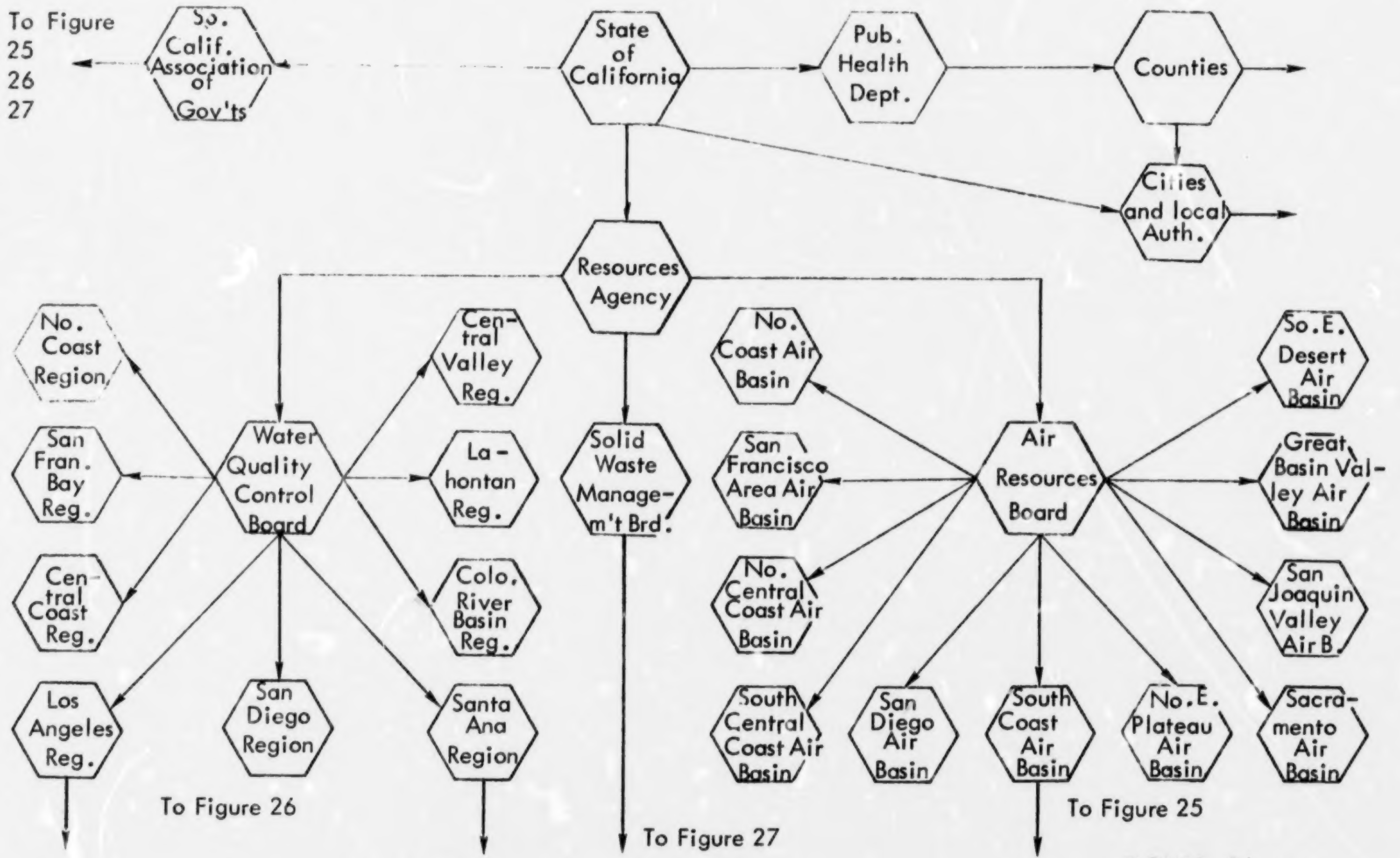
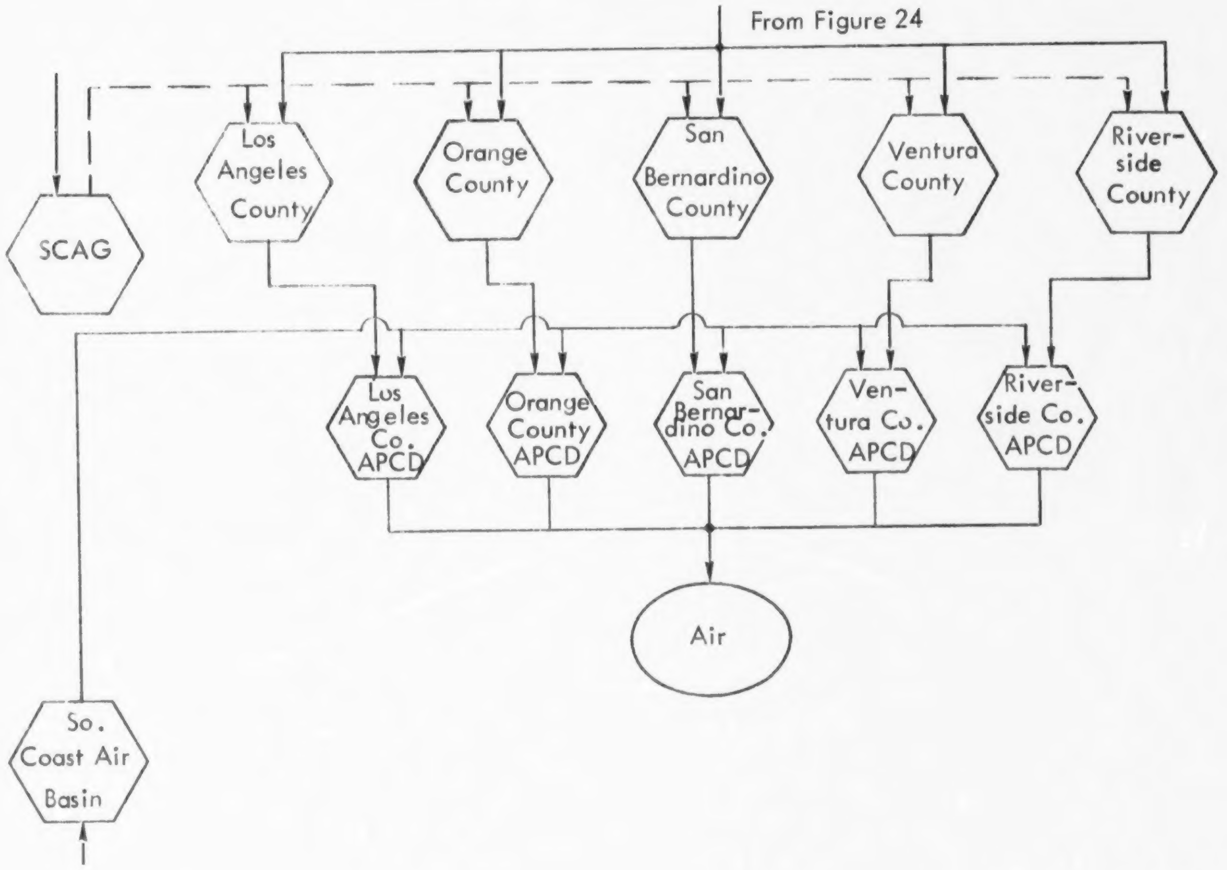
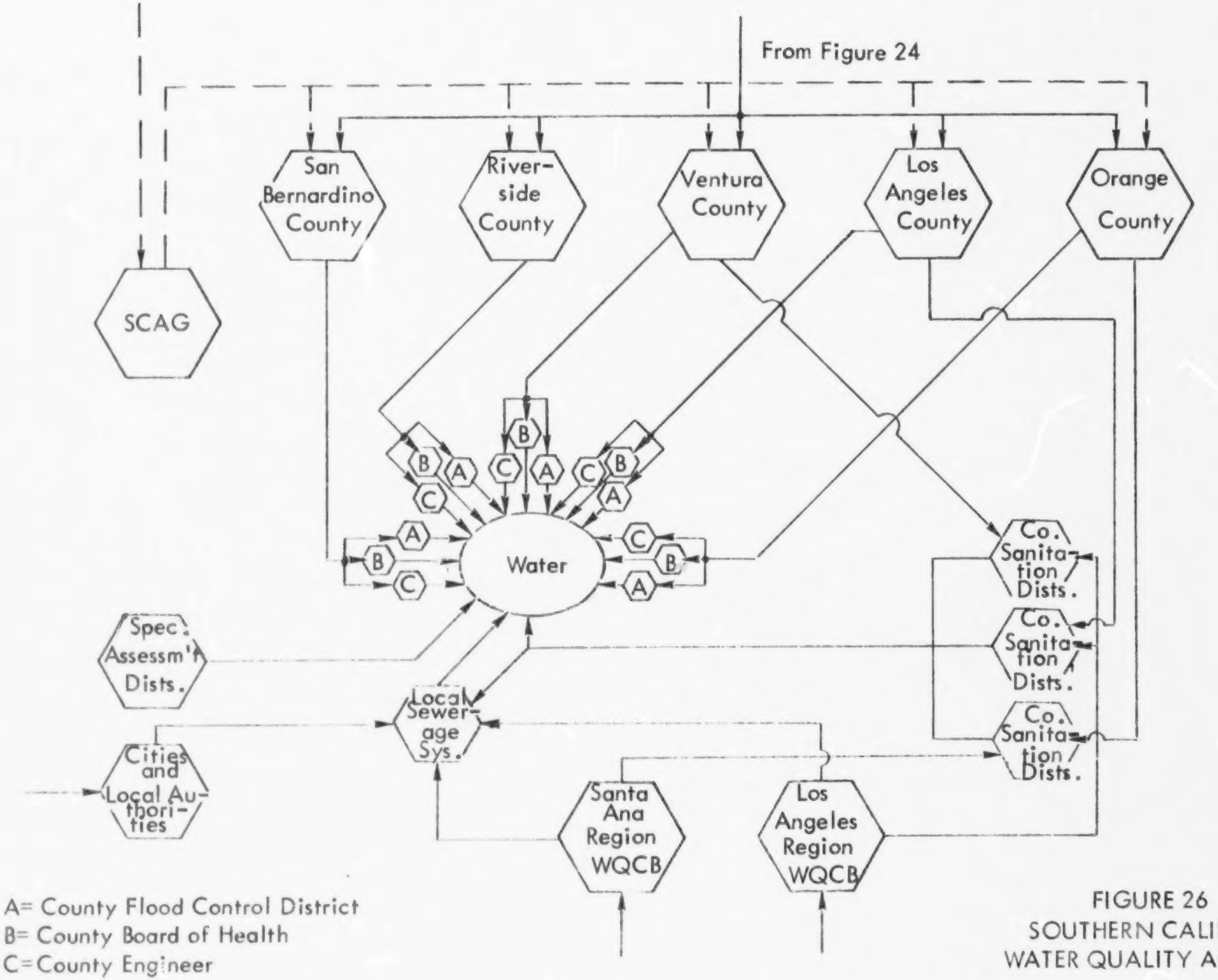

To Figure
25
26
27
So. Calif. Association of Gov'ts
State of California
Pub. Health Dept.
Counties
Cities and local Auth.
Resources Agency
Water Quality Control Board
No. Coast Region
San Fran. Bay Reg.
Central Coast Reg.
Los Angeles Reg.
San Diego Region
Central Valley Reg.
La-hontan Reg.
Colo. River Basin Reg.
Santa Ana Region
To Figure 26
Solid Waste Manage-m't Brd.
To Figure 27
Air Resources Board
No. Coast Air Basin
San Francisco Area Air Basin
No. Central Coast Air Basin
South Central Coast Air Basin
San Diego Air Basin
South Coast Air Basin
No. E. Plateau Air Basin
So. E. Desert Air Basin
Great Basin Valley Air Basin
San Joaquin Valley Air B.
Sacramento Air Basin
To Figure 25

FIGURE 24
STATE AND REGIONAL
ENVIRONMENTAL AGENCIES


From Figure 24
SCAG
Los Angeles County
Orange County
San Bernardino County
Ventura County
Riverside County
Los Angeles Co. APCD
Orange County APCD
San Bernardino Co. APCD
Ventura Co. APCD
Riverside Co. APCD
Air
So. Coast Air Basin

APCD= Air Pollution Control District

FIGURE 25
SOUTHERN CALIFORNIA
AIR QUALITY AGENCIES


From Figure 24
SCAG
San Bernardino County
Riverside County
Ventura County
Los Angeles County
Orange County
A
B
C
Water
Co. Sanitation Dists.
Co. Sanitation Dists.
Co. Sanitation Dists.
Spec. Assessm't Dists.
Local Sewerage Sys.
Cities and Local Authorities
Santa Ana Region WQCB
Los Angeles Region WQCB

A= County Flood Control District
B= County Board of Health
C=County Engineer

FIGURE 26
SOUTHERN CALIFORNIA
WATER QUALITY AGENCIES

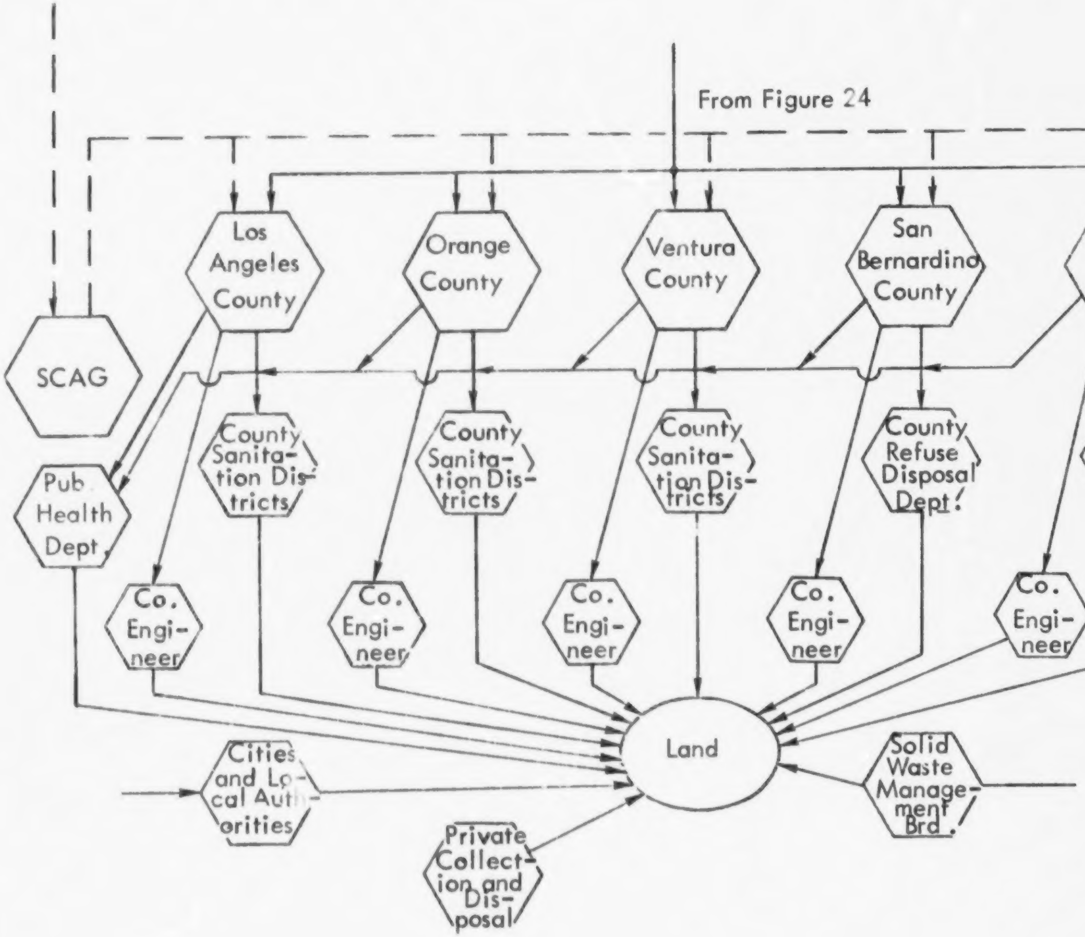

From Figure 24
SCAG
Los Angeles County
Orange County
Ventura County
San Bernardino County
Riverside County
Pub. Health Dept.
County Sanitation Districts
County Sanitation Districts
County Sanitation Districts
County Refuse Disposal Dept.
County Road Dept.
Co. Engineer
Co. Engineer
Co. Engineer
Co. Engineer
Co. Engineer
Land
Cities and Local Authorities
Private Collection and Disposal
Solid Waste Management Brd.

FIGURE 27
SOUTHERN CALIFORNIA
SOLID WASTE MANAGEMENT
AGENCIES

MAJOR INTERMEDIA AIR POLLUTANTS

Long before the Los Angeles Metropolitan Region became a population center, the potential for a severe air pollution problem existed in the area. The first recorded reference to air pollution in the Los Angeles area dates from 1542. In that year Juan Rodrigues Cabrillo observed the smoke from Indian camp fires to rise a few hundred feet into the air and then level out. (We know now of the temperature inversion layer.)Because of this phenomenon Cabrillo called what is now San Pedro Bay,"La Bahia de los Fumos"- The Bay of Smoke.[312] The temperature inversion layer sits like a lid below the tops of the surrounding mountains and keeps the air mass in the basin from being moved out and replaced by cleaner air.[301]

Emissions

This inversion layer helps to contain the 16,600 tons of air pollutants which are produced and emitted daily in the region. The emitters of these pollutants fall into two large classes, either stationary or mobile sources.[301] Mobile sources, particularly motor vehicles, are the major sources of hydrocarbons, NO_x and CO. The major sources of SO_x and particulates, on the other hand, are the stationary sources, even though motor vehicles are significant contributors of these emissions.[299] Motor vehicles account for 87 percent of the highly reactive hydrocarbons, 68 percent of all hydrocarbons, 75 percent of the NO_x, 34 percent of the particulates, 16 percent of the SO_x, and 93 percent of the CO. The use of organic solvents in such operations as dry cleaning, cleaning and degreasing of metal parts, pesticide application,etc. accounts for 6 percent of the highly reactive hydrocarbons and 17.5 percent of the total; while the production, refining and marketing account for 4 percent and 9.5 percent,respectively. The production and use of solvents,along with motor vehicles, produce 97 percent of the highly reactive hydrocarbons and 95 percent of the total hydrocarbons in the Los Angeles Metropolitan Region.[299]

The combustion of fuels by stationary sources in the region accounts for 18 percent of the NO_x emitted, 8.5 percent by steam power plants and 9.5 percent by all other fuel combustion. With the 75 percent emitted by motor vehicles,93 percent of the NO_x emitted is accounted for.

The emission of SO_x is the only category of air pollutants to which motor vehicles are not the major contributor. In fact motor vehicles are only the fourth largest SO_x emitters in the region. Stationary sources emit 84 percent of the SO_x, of which 37 percent is contributed by the chemical industry, 18 percent by the petroleum industry (production, refining, and marketing), and 16 percent by the combustion of fuels (13 percent by power plants and 3 percent by all other fuel combustion).[299]

The emissions of particulate material are divided between the stationary sources, with 54.5 percent of the total, and mobile sources, with 45.5 percent of the total. Particulate emissions from motor vehicles amount to 74 percent of the mobile source contribution and 34 percent of the total. The remainder of the particulate emissions are spread out fairly evenly thoughout the other sources, so much so that seven out of the eleven source categories must be included before 90 percent of these emissions are accounted for.

The situation for CO emissions is the exact opposite with almost all these emissions (97 percent) coming from motor vehicles and virtually all (99+ percent) from mobile sources.[299]

All of the emissions in the region have been tabulated and are presented in Table 39.

Standards and Regulations

The present California standards for air quality are among the most stringent in the country. A summary of the California and Federal Standards is given in Table 40. On the whole, the State has left the task of controlling stationary source emissions to the local air pollution control districts. However, the State Attorney General and the Air Resources Board can act either at the request of the local district or on their own initiative.[299] The State has maintained direct control and right of enforcement of emission standards for mobile sources.[299] This dichotomy of control is necessary because the movements of mobile sources between districts would otherwise render control and enforcement impossible.

Mobile Sources

All motor vehicles of model year 1955 and later are required to have emission control devices. A certificate of compliance must be obtained from the California Highway Patrol before any vehicle may be initially registered or re-registered to a new owner. Emission control devices must be approved by the Air Resources Board for durability and reliability as well as emission control before the vehicle may be sold in Califomia. All vehicles, 1955 and later, are subject to random roadside emissions tests,and vehicles which exceed the standard must be repaired in thirty days. At the present time the Air Resources Board has not set standards for 1955 through 1965 model vehicles but these are expected in the near future. In addition to the emissions of the colorless gases such as CO, NO_x, SO_x, and hydrocarbons, emissions of visible pollutants are also regulated. No vehicle may emit smoke which is darker than Number One on the Ringlemann Chart for more than ten seconds if the car was sold new after January 1, 1971, or darker than Ringlemann Number Two if sold new prior to January 1, 1971.[299]

The present enforcement techniques have been successful in reducing hydrocarbon contributions to the atmosphere from motor vehicles by 37.5 percent, and carbon monoxide by 31 percent. However, these techniques have resulted in an increase of 12.8 percent in NO_x emissions.[301]

TABLE 39[299]

SOUTH COAST AIR BASIN
COMPARISON OF EMISSIONS BY COUNTY
(TONS PER DAY)
1970

County	Organic Gases		Particulate Matter	Oxides of Nitrogen	Sulfur Dioxide	Carbon Monoxide
	Highly Reactive	Total				
Los Angeles[a]	1290	2380	129	1140	250	8080
Orange	245	379	23	190	15	1620
Riverside	59	107	19	47	4	433
San Bernardino[a]	92	144	33	86	40	596
Santa Barbara[a]	27	47	4	23	1	72
Ventura	73	135	29	76	5	477
TOTAL[b]	1790	3200	235	1570	315	11300

a) That portion of the county within the South Coast Air Basin.
b) Totals may not agree due to rounding errors.

TABLE 40
AMBIENT AIR QUALITY STANDARDS APPLICABLE IN CALIFORNIA

Pollutant	Averaging Time	California Standards		Federal Standards		
		Concentration[7]	Method[1]	Primary[2,7]	Secondary[3,7]	Method[5]
Photochemical Oxidants (Corrected for NO_2)	1 hour	0.10 ppm (200 g/m^3)	Neutral Buffered KI	160 g/m^3 [8] (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hours	10 ppm (11 mg/m^3)	Non-Dispersive Infrared Spectroscopy		Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hours	--		10 mg/m^3 (9 ppm)		
		40 ppm (46 mg/m^3)		40 mg/m^3 (35 ppm)		
Nitrogen Dioxide	Annual Average	--	Saltzman Method	100 g/m^3 (0.05 ppm)	Same as Primary Standard	Colorimetric Method Using NaOH
	1 hour	0.25 ppm (470 g/m^3)		--		
Sulfur Dioxide	Annual Average	--	Conductimetric Method	80 g/m^3 (.03 ppm)	60 g/m^3 (0.02 ppm)	Pararosaniline Method
	24 hours	0.04 ppm (105 g/m^3		365 g/m^3 (0.14 ppm)	260 g/m^3 (0.10 ppm)	
	3 hours	--		--	1300 g/m^3 (0.5 ppm)	
	1 hour	0.5 ppm (1310 g/m^3)		--	--	
Suspended Particulate Matter	Annual Geometric Mean	60 g/m^3	High Volume Sampling	75 g/m^3	60 g/m^3	High Volume Sampling
	24 hours	100 g/m^3		260 g/m^3	150 g/m^3	

TABLE 40 299 (cont.)

Pollutant	Averaging Time	California Standards Concentration[7]	California Standards Method[1]	Federal Standards Primary[2,7]	Federal Standards Secondary[3,7]	Federal Standards Method[5]
Lead (Particulate)	30 day Average	1.5 g/m^3	High Volume Sampling Dithizone Method	--	--	--
Hydrogen Sulfide	1 hour	0.03 ppm (42 g/m^3)	Cadmium Hydroxide Stractan Method	--	--	--
Hydrocarbons (Corrected for Methane)	3 hours (6-9 a.m.)	--	--	160 g/m^3 (0.24 ppm)	Same as Primary Standard	Flame Ionization Detection Using Gas Chromatography
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to 10 miles when the relative humidity is less than 70%				

NOTES:

1. Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.
2. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).
3. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.
4. Federal standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.
5. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" to be approved by the EPA.

TABLE 40[299] (Cont.)

NOTES: cont.

6. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle.
7. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury.
8. Corrected for SO_2 in addition to NO_2.

Stationary Sources

As noted previously, the burden of control of stationary source emissions has been left to the individual county air pollution control districts. This diversity of control could lead to polluters seeking areas of least regulation. However, the five county APCD's involved in the study region have almost identical regulations and such action is discouraged. The regulations of the Los Angeles County APCD are the most stringent in the State and have been used by other APCD's as a model.[299] Table 41 is a summary of regulations of the five County Air Pollution Control Districts as of January 7, 1972. The sixth column, marked "Proposed", is a summary of proposed additions or modifications formulated by the Air Resources Board and which each APCD in the region will consider and strengthen or make effective no later than January 1, 1973.[299]

In Los Angeles County the regulations have been effective in reducing the emissions of hydrocarbons by 67.5 percent; of NO_x by 52.5 percent; of SO_x by 90 percent; of CO by 99.5 percent; and of particulates by 89 percent. In all, the Los Angeles County APCD regulations have resulted in the prevention of the emission of 6,870 tons per day of pollutants.[301]

Control Strategies

The Clean Air Act of 1970 required that each State submit a plan for the implementation, maintenance and enforcement of the national ambient air quality standards for that State by January 31, 1973. The plan submitted by the State of California was found to be unacceptable in part to the EPA. This plan includes an estimation of the effects of the control strategies on carbon monoxide, oxides of nitrogen, oxidants (which are believed directly proportional to hydrocarbons), particulate matter, and oxides of sulfur.[299]

Carbon Monoxide In the Los Angeles Metropolitan Region approximately 11,200 tons per day of carbon monoxide were emitted in 1970. The California Implementation Plan estimates that, in order to meet the Federal standards, these emissions would have to be cut 78 percent,or reduced to 2,500 tons per day. It further estimates that, if the State's plan were fully implemented, the region's emissions will be reduced to 2,300 tons per day. This would be accomplished by controls on the following source areas: 1) open burning of solid waste is prohibited (already in effect) and backyard burning at single and two family dwelling units, now in effect in some areas, will be completely in effect by 1975. This will reduce carbon monoxide emissions by 40 tons per day; 2) agricultural burning controlled by material and climatic conditions to assure good combustion should result in a reduction of 5 tons per day in carbon monoxide emissions in 1975; 3) motor vehicle emission controls should result in a reduction of 6,030 tons per day in 1975 carbon monoxide emissions; 4) ship and airplane emissions under control of the Federal Government should have reduced carbon monoxide emissions 210 tons per day; 5) periodic vehicle emission inspection and mandatory maintenance should reduce carbon monoxide emissions by 1,600 tons per day in 1975; 6) conversion of one-third of all gasoline powered motor vehicles to use gaseous fuel should produce

TABLE 41

SUMMARY OF RULES AND REGULATIONS SOUTH COAST AIR BASIN APCD'S[299]

Rules and Regulations	Los Angeles	Orange	Riverside	San Bernardino	Ventura	Proposed
Particulate Matter						
Grain Loading	0.2 gr/scf for gas flow rates 1000cfm	0.3 gr/scf max	0.3 gr/scf max.	0.3 gr/scf max.	0.3 gr/scf max.	0.2 gr/scf max.
Process Weight Dust and Fumes	30 lb/hr max for process wt. 10^b lb/hr	40 lb/hr max. for process wt. 60,000 lb/hr	40 lb/hr max for process wt. 60,000 lb/hr	40 lb/hr max. for 60,000 lb/hr or 0.1 gr/scf max. for gas vol 70,000scfm	92.7 lb/hr max. for process wts. 6,000,000 lb/hr	30 lb/hr max.
Combustion Contaminants	0.3 gr/scf max.	0.3 gr/scf max.	0.3 gr/scf max.	0.3 gr/scf max.	0.3 gr/scf max.	0.1 gr/scf max.
Fuel Burning Equipment	10 lb/hr max.	10 lb/hr max.	10 lb/hr max.	10 lb/hr max.	N. R.	10 lb/hr max.
Incinerators	0.1 gr/scf	N. R.*	N. R.	N. R.	N. R.	0.1 gr/scf
Visible Emissions	Ringlemann No. 1	Ringlemann No. 2	Ringlemann No. 2	Ringlemann No.2	Ringlemann No. 2	Ringlemann No. 1 for less than 3 min/hr
Burning						
Agricultural	Per state guidelines	Per state guidelines	Per state guidelines	Per state guidelines	Per state guidelines	
Open Fires	Banned	Banned	Banned	Banned	Banned	Banned
Incinerators	Single chamber Banned	Single chamber Banned	Single chamber Banned	Single chamber Banned	Single chamber Banned	--
Orchard Heaters	Acceptable brands Specified	Acceptable Brands specified	Acceptable Brands specified	Acceptable Brands specified	Acceptable Brands specified	--

* N. R. = No regulation in effect.

TABLE 41 (cont.)

Rules and Regulations	Los Angeles	Orange	Riverside	San Bernardino	Ventura	Proposed
Petroleum Products						
Gasoline loading trucks	Vapor controls required	Vapor controls required	Vapor controls required	Vapor controls required	Vapor controls required	Vapor controls required
Storage of Petroleum Products	Control equipment specified	Control equipment specified	Control equipment specified	Control equipment specified	Control equipment specified	Control equipment specified
Organic liquid loading	Controls specified	Controls specified, limited to gasoline	Controls specified, limited to gasoline	Controls specified, limited to gasoline	Controls specified	Controls specified
Oil-effluent water separators	Vaporless recovery device required. Control equipment specified	Vaporless recovery device required. Control equipment specified	Vaporless recovery device required. Control equipment specified.	Vaporless recovery device required. Control equipment specified.	Vaporless recovery device required.	Vaporless recovery device required.
Solvents						
Organic solvents	Emissions controlled	Emissions controlled	Emissions controlled	N. R.	N. R.	Emissions controlled
Disposal and Evaporation	$1\frac{1}{2}$ gal/day of reactive solvent	$1\frac{1}{2}$ gal/day of reactive solvent	$1\frac{1}{2}$ gal/day of reactive solvent	$1\frac{1}{2}$ gal/day of reactive solvent	N. R.	$1\frac{1}{2}$ gal/day of reactive solvent
Architectural Coatings	Restricts sale and use of reactive coatings	Restricts sale and use of reactive coatings	Restricts sale and use of reactive coatings	Restricts sale and use of reactive coatings	N. R.	Restricts sale and use of reactive coatings

TABLE 41 (cont.)

Rules and Regulations	Los Angeles	Orange	Riverside	San Bernardino	Ventura	Proposed
Sulfur						
Sulfur Recovery Plants	500 ppm SO_2 10 ppm H_2S 200 lb/hr SO_2	Exempted	Exempted	Exempted	N. R.	500 ppm SO_2 200 lb/hr SO_2 10 ppm H_2S
Sulfuric Acid Plants	500 ppm SO_2 200 lb/hr SO_2	Exempted	Exempted	Exempted	N. R.	500 ppm SO_2 200 lb/hr SO_2 1974 10 ppm H_2S
Sulfur Compounds	0.2% SO_2 by volume max.	0.2% SO_2 by volume max.	0.2% SO_2 by volume max.	0.1% SO_2 by volume max.	0.2% SO_2 by volume max. 0.1 ppm, 24 hr ave. ground-level	500 ppm SO_2 for new 1973 and for 1975 existing
Sulfur Content of Fuels	50 gr/100 ft gaseous fuels 0.5% wt. liquid or solid fuel	50 gr/100 ft^3 fuels, 0.5% wt liquid or solid fuels	50 gr/100 ft^3 gaseous fuels, 0.5% wt liquid or solid fuels	50 gr/100 ft^3 gaseous fuels, 0.5% wt liquid or solid fuels	N. R.	50 gr/100 scf gaseous 15 gr/100 scf nat'l gas 0.5% wt liquid or solid
Fuel Burning Equipment	New equipment limited to 200 lb/hr SO_2	New equipment limited to 200 lb/hr SO_2	New equipment limited to 200 lb/hr SO_2	New equipment limited to 200 lb/hr SO_2	New equipment limited to 200 lb/hr SO_2	(all equipment) 200 lb/hr SO_2
Oxides of Nitrogen						
Fuel Burning Equipment	225 ppm liquid fuel 325 ppm solid fuel	New equipment limited to 140 lb/hr	New equipment limited to 140 lb/hr	New equipment limited to 140 lb/hr	250 ppm or 20 ton/day per source	125 ppm gaseous fuel 225 ppm liquid or solid fuels

TABLE 41 (cont.)

Rules and Regulations	Los Angeles	Orange	Riverside	San Bernardino	Ventura	Proposed
Carbon Monoxide		N. R.	N. R.	N. R.	N. R.	2000 ppm max.
Other Regulations		N. R.	N. R.	N. R.	N. R.	
Asphalt Air Blowing	Controls required on all equipment					Gases processed equivalent to incineration at 1400°F for 0.3 seconds
Reduction of Animal Matter	Requires temperatures 1200°F for at least 0.3 seconds	Requires temperatures 1200°F for at least 0.3 seconds	Requires temperatures 1200°F for at least 0.3 seconds	Requires temperatures 1200°F for at least 0.3 seconds	Requires temperatures 1300°F for at least 0.4 seconds	Requires temperatures 1200°F for at least 0.3 seconds
Vacuum Producing Devices or Systems	Limits amount of organic material emitted	N. R.	N. R.	N. R.	N. R.	Emission 3 lb/hr unless emission reduced by 90%
Flourine Compounds	N. R.	Prohibits injury to property of others	Prohibits injury to property of others	Prohibits injury to property of others	N. R.	--

TABLE 41 (cont.)

Rules and Regulations	Los Angeles	Orange	Riverside	San Bernardino	Ventura	Proposed
Circumvention	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	--
Nuisance	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	--

a reduction of 1330 tons per day in carbon monoxide emissions by 1975; and 7) the optimistic goal of a 20 percent reduction in traffic by extensive use of public transportation, car pooling, and changes in work schedule, should result in 550 tons per day reduction in carbon monoxide by 1975. The total of these reductions is more than 9,700 tons per day, while population growth should increase emissions about 740 tons per day. The actual reduction will then be about 9,000 tons/day leaving approximately 2300 tons per day of carbon monoxide emissions in 1975.[299]

Oxides of Nitrogen The 1970 emissions of oxides of nitrogen into the atmosphere of the study region amounted to about 1570 tons per day. In order to meet the Federal ambient air quality standards for 1975 this level must be reduced to 830 tons per day or a reduction of 47 percent. The implementation plan recommends a six-step strategy for achieving this reduction. The six steps include: 1) bans on open burning of solid wastes and on backyard burning at single and two family dwelling units, to be in effect by 1975 in those areas not already included. This will reduce NO_2 emissions by about 3 tons per day; 2) emissions from new fuel combustion equipment will be limited to 140 pounds per day and from large fuel combustion equipment to 125 ppm NO_2 for sources using gaseous fuel and 225 ppm NO_2 for sources using liquid or solid fuel--the measures are expected to eliminate 25 tons per day of NO_2; 3) the State's current motor vehicle emission control plan is expected to reduce NO_2 emissions by 450 tons per day; 4) emission control from airplanes and ships, now the responsibility of the Federal government, is expected to eliminate emissions from these sources and reduce NO_2 emissions by 20 tons per day; 5) the conversion of one-third of the gasoline-powered motor vehicles to the use of gaseous fuels will produce a reduction of 200 tons per day of NO_2; 6) public transportation, car pooling, etc. to reduce motor traffic by 20 percent will result in a reduction in NO_2 emissions of 130 tons per day. If all these expectations are met, they will result in a reduction in 1975 of about 830 tons per day of NO_2, while the population growth will increase these daily emissions about 105 tons, and, if the program of mandatory vehicle inspection and maintenance is implemented, an increase of another 45 tons per day can be expected. The overall result is a net decrease of about 680 tons per day. This leaves about 890 tons per day which is about 60 tons per day more than the allowable emissions for 1975. However, by 1977 emission controls on used cars will result in an 80 ton per day reduction, to produce total NO_2 emissions of about 810 tons per day, which is below the level needed to meet the Federal standard.[299]

Oxidant Oxidant is not emitted as a pollutant but rather it is the result of photo chemical reaction. It is therefore assumed that the best control strategy for oxidant is to control the reactive hydrocarbons. The sources of highly reactive hydrocarbons emitted about 1785 tons per day within the region in 1970. To comply with the Federal standards, these emissions must be reduced to 215 tons per day, a reduction of 88 percent. In the State's attempt to meet this standard, they have proposed an multi-step approach to the problem. These steps are: 1) the control of evaporative emissions of organic materials in marketing operations to reduce highly reactive organic gas emissions by 65 tons per day; these controls include vapor recovery systems for:

loading tank trucks at bulk plants, storage tanks at service stations, and vehicles at service stations; 2) a reduction of 5 tons per day is expected from more stringent and broader regulations concerning the use and disposal of organic solvents; 3) continuation of the current motor vehicle emission control program will decrease highly reactive hydrocarbon emissions from ships and aircraft by 30 tons per day; 4) periodic vehicle inspection and mandatory maintenance, if the program is implemented, could reduce emissions by about 70 tons per day; 5) a reduction of 95 tons per day is possible by the implementation of the proposed program to retrofit 1966 through 1969 model used motor vehicles with fuel evaporative emission control equipment; 6) if the program to convert one-third of the gasoline-powered motor vehicles to gaseous fuels is implemented, a reduction of 75 tons per day will follow; and 7) traffic reductions through the means described for other pollutants, would result in a reduction of 85 tons per day. All of these reductions will reduce emissions by 1425 tons per day. Population growth will add 115 tons per day to produce a net reduction of 1310 tons per day, and a new total of 475 tons per day. This is 120 percent more than that amount estimated by the State which would be permissible under the Federal standard.[299]

This is one of the points which made the State's plan unacceptable, since the EPA believes the Federal standards can be met. Also, the EPA estimates that emissions must be cut to 161 tons per day rather than 215 tons per day to meet the Federal requirement.

The EPA rewrote the oxident portion of the control strategy and included gasoline rationing during the six months of high air pollution, May through October. The proposal calls for a reduction in gasoline consumption by about 80 percent.[310] The EPA plan is summarized in Table 42.

Particulate Matter In 1970, about 235 tons per day of particulate matter was directly emitted in the region, with the highest annual geometric mean observed being 127 g/m^3. About 20 percent of this concentration comes from natural sources leaving about 480 tons per day or 100 g/m^3 from controllable sources. Comparing this adjusted figure with the Federal secondary standard of 60 g/m^3 indicates 40 percent of these emissions must be controlled. Not all particulate matter is directly emitted, however, since a large fraction present is the product of the photochemical reaction. The strategy for control of particulate matter then requires both direct control and control of the photochemical reaction.[299]

A nine-step plan has been proposed for direct control. These are: 1) additional control of visible emissions from the petroleum industry is expected to reduce particulate emissions by 1 ton per day; 2) more stringent grain loading and visible emission regulation of organic solvents (mainly for surface coating and spraying operations) will reduce emissions by 6 tons per day; 3) particulate emission from metallurgical operations are expected to decrease about 6 tons per day as a result of more stringent regulations concerning visible emission, process weight and grain loading; 4) mineral operation emissions should be reduced by about 7 tons per day because of the enactment of more stringent regulations concerning visible emissions, process weight and grain loading; 5) by banning open burning for solid waste disposal, banning backyard burning at single and two family

TABLE 42
SUMMARY OF FEDERAL PLAN FOR HYDROCARBON REDUCTION

The Emissions

Estimated 1977 hydrocarbon emissions without additional controls in Los Angeles, Orange, Riverside, San Bernardino, Ventura and Santa Barbara Counties:

Source	Tons/day
Motor vehicles	+442
Stationary sources	+215
Aircraft	+ 24
TOTAL	+681 tons/day

The Emission Reduction

Estimated elimination of hydrocarbons through proposed motor vehicle controls:

Limit motor vehicle vacuum spark advance (to be implemented by the State of California)	- 19
Motor adjustments required at annual vehicle inspection	- 39
Control evaporation from motor vehicles	- 26
Require gaseous fuel in certain fleet vehicles	- 13
Install catalytic hydrocarbon converters on all vehicles	- 81
Ration gasoline from May through October 31	-198
TOTAL REDUCTION IN MOTOR VEHICLE HYDROCARBON EMISSIONS	-379

Estimated elimination of hydrocarbons through proposed controls on stationary sources:

Control evaporation from gasoline storage tanks and vehicle gasoline tank filling operation	- 65
Limit quantity and method of use of hydrocarbon compounds in industry	- 45
Eliminate reactive hydrocarbons in industrial "degreasing" operations	- 25
Control hydrocarbon use in dry cleaning plants	- 6
TOTAL REDUCTION STATIONARY SOURCE HYDROCARBON EMISSIONS	-141

THE SUMMARY

Total hydrocarbon emissions	+681
Total reduction from controls listed above	-520
REMAINING HYDROCARBON EMISSIONS AFTER IMPLEMENTATION OF CONTROLS	+161 tons/day

dwelling units, and placing more stringent regulations on emissions from incinerators, an estimated 6 tons per day of particulates will be removed from the atmosphere; 6) more stringent regulations on fuel burning operations (with regard to visible emissions and grain loadings) are expected to eliminate 5 tons per day; 7) control of emissions from ships and aircraft by the Federal government should lead to a reduction of 30 tons per day; 8) the use of low lead motor fuel will remove 40 tons per day; and 9) a 20 percent reduction in traffic which will hopefully be realized through the use of public transportation, car-pooling, and changes in work schedules would yield a reduction of 9 tons per day. This total reduction amounts to 110 tons per day, but the net reduction is only 95 tons per day since population growth is expected to increase emissions 15 tons per day.[299]

The implementation of control of hydrocarbons and the resultant decrease in the photochemical reaction will probably reduce photochemical particulates by 180 tons per day. The total reduction in particulate matter will then be 275 tons per day, and the remaining 200 is well below the 290 tons per day necessary to meet the standard.[299]

Sulfur Dioxide The emission of sulfur dioxide in 1970 totalled 315 tons per day. In order to bring the region into line with the Federal standards, this figure must be reduced to 200 tons per day. The plan to effect this reduction has five steps: 1) the regulation of emissions of sulfur compounds will be changed from 2000 to 500 parts per million of sulfur dioxide; the implementation of this regulation should reduce emissions by some 10 tons per day, mostly from the catclytic cracking process; 2) sulfur dioxide emissions from sulfur recovery plants and sulfuric acid plants will be additionally controlled; these controls should reduce sulfur dioxide emissions by 100 tons per day; 3) the sulfur content of natural gas will be limited to 15 grains per 100 cubic feet and the sulfur content of oil will be limited to 0.5 percent in areas where it is presently uncontrolled; these controls should reduce emissions by about 6 tons per day; 4) if one-third of the gasoline-powered motor vehicles were converted to gaseous fuel, sulfur dioxide emissions would be reduced by 10 tons per day; and 5) the traffic reduction plans (by use of public transportation, car pooling, and changes in work schedules) which will hopefully reduce traffic by 20 percent will then reduce emissions by 10 tons per day. The sum of these reductions is about 140 tons per day. Population will increase emissions by 20 tons per day, causing a net decrease of 120 tons per day, and leaving about 200 tons per day compared to the 240 tons per day estimated to be the quantity permitted by the Federal standard.[299]

Intermedia Transfer

Some of the air pollution control strategies mentioned above will transfer the pollutant to another medium. In some instances this transfer is obvious, as in the case of an industrial plant using a wet scrubber in an air stream. The pollutant is then removed from the air and placed directly into the water. In another instance a process change might be used to reduce the emission, but result in discharging the pollutant to receiving waters. Here the pollutant is not transferred directly but it is nonetheless transferred. Most of the elements of the proposed control strategy will affect another medium to some extent.

Present Situation, Mobile Sources At the present time there appears to be no methodology whereby the pollutants produced and emitted by mobile sources can be transmitted to another medium by man controlled processes. The only controls which are now in use, or feasible for use in the near future, are either a process change or a breakdown of the components of pollutants. A process change would mean the substitution of another fuel, such as natural gas or hydrogen, or the substitution of an alternative means of propulsion such as steam. These changes would undoubtedly have various positive effects on the air quality of the region. Since they would reduce the total emissions rather than divert them to another medium, an alternative to a process change would be treatment of the effluent stream which, because the source is mobile, makes intermedia transfer difficult. Any system which removes the pollutant from the air stream would require the residue to be stored in the vehicle and periodically removed. Designers of emission control systems have found it simpler and more economical to convert the polluting substance to some non-polluting gas. For example, hydrocarbons can be burned in an after-burner and reduced to H_2O and CO_2, or NO_x can be converted to N_2 and O_2, all of which are components of the atmosphere. These systems are partially effective in dealing with motor vehicle emissions and do not have any intermedia possibilities.

Present Situation, Stationary Sources The stationary sources are better candidates for intermedia transfer. The largest intermedia transfer in the Los Angeles Metropolitan Region at the present time results from the change from solid waste incineration to sanitary landfilling. The banning of backyard burning was one of the first major acts taken by the Los Angeles County APCD.[301] The Los Angeles County APCD estimates that the use of landfilling keeps 250 tons per day of hydrocarbons (90 tons of which are highly photochemically reactive) out of the air.[301]

The Los Angeles Metropolitan Region is aptly suited to the large scale use of landfill since there are numerous canyons which are excellent sites for sanitary landfill operation if the work is conducted with concern for esthetics. When the landfill is complete, the area may be used for other purposes and so creates an asset from what would otherwise have been a pollution source.[300]

Table 43 is a summary of the air pollution control equipment in use in Los Angeles County and the intermedia effects of this equipment. The information was obtained through discussion with the Los Angeles County Air Pollution Control District.[323] Although much of the residue created is recycled or is disposed in landfills, some transfers to water do take place. The rendering industry uses scrubbers which provide a high transfer of particulate hydrocarbons and some other pollutants to water. Wastes from coke handling in petroleum refineries are controlled by scrubbers although a large portion of the scrubber water is reused in the process. Although 50 percent of the hot asphalt industry still use scrubbers, this method of treatment is being phased out because of stricter standards which are difficult to meet with scrubbers. Less than 10 percent of the metallurgical sources still use scrubbers although they are also being phased out in this region. The proposed controls on dry cleaning establishments requiring activated carbon controls on hydrocarbon emissions will result in some transfer to water through the

TABLE 43[323]

AIR POLLUTION CONTROLS AND RESIDUES, LOS ANGELES COUNTY, CALIFORNIA

SIC Code	Description	Controls	Residues[a]
01	Agricultural Burning	Banned completely in basin Burn days only in high desert area	Solid waste to landfill
	Orchard heaters	Banned - now use pans	None
20	Food industry	Afterburners for hydrocarbons	Gaseous combustion products
204	Feed mills and grain elevators	Cyclones and baghouses	Solid residue Animal feed residues - Recycled back into product Food grain residues mostly used in animal feed.
2077	Rendering industry	Scrubbers (particulates and condensable hydrocarbons)	Residues to water - to county sanitation districts or city sewer systems.
2819	Sulfuric acid plants	SO_x control by dimethylaniline, amine or similar process (see SO_x control section in section V)	Regenerative process burns H_2S to SO_2 then adsorbs SO_2 on amine to yield H_2SO_4, the amine is regenerated. H_2SO_4 is sold or used.
2834	Pharmaceuticals	Baghouses	Solid waste reuse in product or if not re-usable deep well disposal because of hazards in landfill disposal.
2911	Petroleum refining coke handling	Hydrocarbons - afterburners scrubbers	Gaseous combustion products in water - mostly back to coke bins.
2951	Hot asphalt	Scrubbers - still 50 percent in use but being phased out can barely meet current standards	Water residue to ponds on premises, overflow to sewers. Every few years dredge ponds - dispose to landfills.

TABLE 43 (cont.)

SIC Code	Description	Controls	Residues
2951 (cont.)		Baghouses more efficient than scrubbers; 50 percent of controls are now baghouses.	Reintroduce fines into asphalt - aids quality of asphalt.
3272	Concrete batching	Process control - 3 percent water addition to process keeps dust down	Water kept in ready-mix.
	Gravel pits	Water sprays	Drain to gravel pit - water recharges ground water.
33-34	Metallurgical processes	Fine emissions - baghouses, scrubbers (less than 10 percent)	Solid waste water
	Zinc wastes	Baghouses	Recycle zinc as valve is high - sold for use in paint, etc. - ZnO_2
5541	Gas stations	New requirements will control vapor loss - will use return systems for auto tank and underground tank filling systems	None
72	Dry cleaning	Hydrocarbons, activated carbon - regenerate with steam for new stricter standards,currently no controls on this many cleaners,lose 50 gal make-up/month	Steam will carry some loss to water Air, water
20-39	Industrial fuel combustion	Afterburners	Gaseous combustion products
		Process methods: alternating fuel-rich,fuel-lean combustion in series with mixing of exhaust air (stoichiometric control) this is only feasible for big fuel users	Gaseous combustion products

TABLE 43 (cont.)

SIC Code	Description	Controls	Residues
20-34	Degreasing operations	Process control: Temperature of operation.	Gaseous combustion products, some increased NO_x in eliminating CO.

a See Table 30 (Pollution Control Alternatives and Quantified Intermedia Impacts) in Section VI for quantitative data on residues created per pound of pollutant removed for the various control processes.

regeneration of the activated carbon with steam.[323]

The majority of the pollution control equipment in Los Angeles County, however, yields solid residues. It is important to note that, since almost all water discharges in Los Angeles County are to sewer systems, intermedia transfer to water is confined largely to the discharges from the two major treatment plants. The City of Los Angeles has been ordered to stop discharging sewage sludge to Santa Monica Bay (see water discussion in this section) and secondary treatment is being planned for Basin treatment plants. Even so, at the present time a large portion of the wastes discharged to the sewer system, not removed by treatment, finds its way to the ocean and thus may effect air intermedia transfer.

Projected Situation

Carbon Monoxide If the carbon monoxide controls which have been discussed earlier are put into effect, an intermedia transfer will result. The ban on open burning in areas not already included will most likely result in an increase in the quantity of solid waste placed in landfills, thereby transferring the pollutant from the air to the land. The other control strategies under consideration involve mobile sources and, as a rule, do not lead to intermedia transfer.

Oxides of Nitrogen Again, the only transfer is from the ban on open burning. Some transfer is possible due to the limitation on emissions of new fuel combustion sources, but it appears that these emissions will be controlled with process changes, such as cooler temperatures and off-stoichiometric combustion, rather than by treating the effluent gas stream.[308,309]

Oxidants The proposed controls, which apply to highly reactive organic gas evaporation controls from both mobile and stationary sources, will result in a recycling of these gases, and also work to offset the cost of new equipment. The captured gases could amount to more than 165 tons per day in 1975.[299]

Particulate Matter At the present time it is not known how much of the reduction in particulate emission will come from treatment of the effluent gas stream and how much will come from process changes. However, that portion which is removed by treatment will find its way either to the sewers, if a wet process is used, or to the land if a dry process is used.

Oxides of Sulfur As with particulates, the method which will be used to effect reductions in emission of sulfur oxide is not known. If the standards are met with a treatment process there will be a residue disposal problem to consider.

MAJOR WATER INTERMEDIA POLLUTANTS

In the Los Angeles Metropolitan Region, the responsibility for treatment and abatement of water pollution falls almost exclusively to the county and municipal organizations. A relatively small portion of the waste water is privately treated and discharged to surface water, probably because of the lack of free flowing surface water which is characteristic of the region. In the past, little control was exerted over what was discharged to the sewers or what was discharged from them. For example, around 1930 the City of Los Angeles,which previously discharged its sewer effluent directly into Santa Monica Bay without treatment, added a bar screen to remove the larger materials from the waste stream. This was the only treatment until the late 1940's,when the City built the Hyperion Sewage Treatment Plant, which uses the activated sludge process. However, the load on the plant increased to about 340 mgd and it was impossible to provide secondary treatment for all the wastewater. Now all the wastes receive primary treatment,with about 25 percent receiving secondary treatment. At the same time, a longer outfall was built to discharge the effluent and sludge further out from shore.

The Hyperion plant previously used vacuum filtration to concentrate the sludge and chemical additions to dry the sludge better. This process proved to be very costly and was abandoned in 1960. It was replaced by the longer outfall. The Water Resources Control Board has ordered that sludge no longer be discharged into the ocean, and an alternative is again needed.[306] This subject will be more thoroughly discussed in the section on intermedia implications of control strategies.

The City of Los Angeles is not the only agency in the region treating sewage. Another large group of agencies are the Los Angeles County Sanitation Districts,whose major plant is the Joint Water Pollution Control Plant. This is a primary plant which averages about 370 mgd of effluent. Smaller plants upstream reclaim waste water and discharge the more concentrated sludge to the Joint Plant,which removes a large portion of the solids by a centrifuge process and sells them to a private firm for conversion to nitro-humus fertilizers.[303] The sludge which is not sold in this way is discharged to the ocean, but this has been ordered stopped,and an alternative must be found. The reclaimed wastewater from upstream plants is used to recharge ground water through spreading grounds in the Whittier Narrows and San Jose Creek.[302]

Until now very few statistics concerning industrial waste discharges have been kept. This lackadaisical approach, however, is now in a state of change. In April, 1972, the Los Angeles County Sanitation Districts instituted a permit system. When an industry applies for a permit, it is required to submit a waste water analysis to show what substances are present in the waste streams, their amounts, the products which the industry produces and what raw materials are used. This permit plan has been initiated to aid in the identification of the sources of various pollutants which must be treated. Similar permit procedures are being started in various areas including the City of Los Angeles.[304] Using estimates made by the City of Los Angeles of concentrations of BOD_5 and suspended solids discharged from various industries, an attempt was made to estimate total discharges from these industries. The results are presented in Table 44 . However, the estimated concentrations are much higher than usually encountered, and so produce total quantities in excess of other estimates for the entire county.

There are, within the region, nearly 100 sewage treatment plants. These plants range in capacity from the very large (nearly 400 mgd) plants run by the City and County of Los Angeles to very small plants which serve hospitals, sheriff stations and similar institutions.[302, 303] These plants are tabulated in Table 45 along with their present average flow, the degree of treatment and method of sludge disposal.

Standards and Regulations

The standards for water quality differ from air quality standards in that the latter can be set for all air, while the standards for water depend upon the intended use for the water,[310] i.e., the standards for recreational waters will be different from those for drinking water, etc. The Federal guidelines for determining State water quality standards were given earlier in this report in the legal section. In addition to those guidelines, the State Water Resources Control Board, through the Los Angeles and Santa Ana Regional Boards, have adopted a set of goals. All the actions of these Boards will be directed toward the implementation of these goals which are:[302, 303]

1) Protect and enhance all State waters, surface and underground, fresh and saline, for present and anticipated beneficial uses including aquatic environmental values.

2) The quality of all surface waters shall be such as to permit maximum recreational use where this use is otherwise practical.

3) All State waters shall be maintained at the highest possible quality; effects as a result of man's activities shall be minimized.

4) Manage municipal and industrial waste waters as part of an integrated system of fresh water supplies to achieve maximum benefit of fresh water resources.

5) Achieve maximum practical use of fresh water through waste water reclamation and reuse by industries, municipalities, and agriculture.

6) Continually upgrade the quality of waste treatment systems to assure consistently high quality effluents.

7) Develop a planned system for water use and waste discharge to assure protection of the aquatic resource for future beneficial uses and achieve harmony with the natural environment.

TABLE 44[222,304,305]
ESTIMATED WATER USE AND BOD$_5$ PRODUCTION BY INDUSTRY IN LOS ANGELES

SIC Code	Industry	Water Use in L.A. Co. & % of Total %	MG/yr.	BOD$_5$ mg/l	BOD in L.A. Co. Ton/Year
201	Meat Products	95	4408	1155	19746
2016	Poultry Dressing Plants	100	546	2213	4690
202	Dairy Products	88	2233	1510	13078
203	Preserved Fruits and Vegetables	76	6280	2213	54771
2035	Pickles, Sauces, and Salad Dressings	100	427	2213	3663
205	Bakery Products	90	635	3021	7438
2065	Confectionery Products	100	378	3021	4432
2079	Shortening and Cooking Oils	55	345	2213	2960
208	Beverages	87	4100	541	8605
20 91 92	Canned and Cured Seafoods Fresh or Frozen Packaged Fish	100	6519	2213	55955
22	Textile Mill Products	94	3588	717	9495
26	Paper and Allied Products	81	114856	676	299556
275	Commercial Printing			1310	
2793	Photo engraving			867	
28	Chemicals and Allied Products	86	64932	298	75463
2844	Toilet Preparations	100	87	1534	519
285	Paints and Allied Products	82	788	1310	4025
2879	Agricultural Chemicals, nec			298	
2891	Adhesives and Sealants	100	544	1310	2782
2899	Chemical Preparations, nec	75	1274	122	606
295	Paving and Roofing Materials	100	447	117	185
30	Rubber and Misc. Plastics Products	80	2817	80	893

TABLE 44 (cont.)

SIC Code	Industry	Water Use in L.A. Co. & % of Total		BOD_5 mg/l	BOD in L.A. Co. Ton/Year
		%	MG/yr		
301	Tires and Inner Tubes	100	668	80	212
32	Stone, Clay, and Glass Products	73	20713	318	23926
325	Structural Clay Products	78	343	117	146
327	Concrete, Gypsum, and Plaster Products	59	4556	117	1936
323	Products of Purchased Glass	100	110	318	820
33 $^{2}_{6}$	Iron and Steel Non ferrous Foundries	91	269	117	123
371	Motor Vehicles and Equipment	99	1067	1262	5270
3711	Motor Vehicles and Car Bodies			1262	
3713	Truck and Bus Bodies			1262	
372	Aircraft and Parts	95	4290	1368	22950
3731	Shipbuilding and Repairing	100	74	1262	364
374	Railroad Equipment			1262	
4469	Water Transportation Services, nec			1262	
554	Gasoline Service Stations			1952	
5812	Eating Places			1122	
7213	Linen Supply			550	
7217	Carpet and Upholstery Cleaning			3021	
7218	Industrial Launderers			576	
7391	Research and Development Laboratories			130	
7542	Car Washes			252	
7699	Repair Services, nec			1262	

TABLE 44 (cont.)

SIC Code	Industry	Water Use in L.A. Co. & % of Total %	MG/yr	BOD_5 mg/l	BOD in L.A. Co. Ton/Year
8071	Medical Laboratories			252	
8072	Dental Laboratories			74	
	TOTAL	83	247994		624609

TABLE 45[302,303]

SEWAGE TREATMENT PLANTS IN THE STUDY REGION

Santa Ana River Basin Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
Western Hills Golf and Country Club	.015	Sec	None
Los Alisos Water District	0.1	Sec	Fertilizer
Rossmoor Sanitation Inc.	1.0	Sec	Discing into fallow field
Irvine Ranch Water District	1.0	Sec	Stockpiled on property
Orange County Industrial Farm	0.008	Pri	Fertilizer
County Sanitation District, Orange Co. Plant #1	49.0 15.0	Pri Sec	Fertilizer
County Sanitation District, Orange Co. Plant #2	80.0	Pri	Fertilizer
City of Seal Beach	0.97	Sec	Landfill
U.S. Naval Weapons Center, Seal Beach	0.25	Pri	Landfill
U.S. Marine Corps Air Station	N/A	Sec	Fertilizer
City of Brea	N/A	Lagoons	Lagoons
City of Redlands	2.4	Sec	Fertilizer
City of San Bernardino Plant #1	7.0	Sec	Fertilizer
City of San Bernardino Plant #2	9.0	Sec	Fertilizer
Campus Crusade for Christ	0.17	Sec	Soil
City of Colton	1.9	Sec	Fertilizer
Glen Helen Rehabilitation Center	0.020	Sec	Landfill
City of Rialto	2.0	Sec	Fertilizer
City of Beaumont	0.40	Sec	Landfill
Big Bear City Community Services District	0.5	Sec	None

TABLE 45 (cont.)

Santa Ana River Basin Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
Big Bear Lake Sanitation District	1.05	Sec	Landfill
DeBenneville Pines	0.015	Sec	None
Running Springs County Water District	0.50	Sec	Landfill
CEDU Foundation	0.005	Sec	None
City of Riverside	16.5	Sec	Fertilizer
Loma Linda University (Riverside)	0.166	Sec	Fertilizer
Rubidoux Community Services District	0.9	Sec	Disposal
Jurupa Community Services District	0.88	Sec	Disposal and Fertilizer
Mira Loma Space Center	0.115	Sec	Disposal
City of Corona	2.75	Sec	Disposal
U.S. Naval Ordnance Laboratory and California Rehabilitation Center	1.52	Sec	Disposal
Edgemont Community Services District	0.2	Sec	Disposal
City of Fontana	2.50	Sec	Fertilizer
Western Pacific Services Company	0.015	Pri	None
Cucamonga County Water District	1.50	Ponds	Ponds
Western Pacific Services Company	0.13	Sec	Ponds
Cities of Ontario - Upland	11.0	Sec	Fertilizer
City of Chino	1.94	Sec	Fertilizer
California Institution for Women	0.14	Sec	Fertilizer
California Institution for Men	0.80	Sec	Fertilizer
City of Elsinore	0.50	Sec	Disposal

TABLE 45 (cont.)

Santa Clara River Basin Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
City of San Buenaventura (Seaside)	2.7	Pri	
Oakview Sanitary District	1.2	Sec	Soil conditioner
Montalvo Municipal Improvement District	0.12	Sec	Landfill
City of Oxnard	9.0	Pri	Landfill
City of Port Hueneme	1.5	Pri	Soil conditioner
City of San Buenaventura (Eastside Plant)	4.0	Sec	Landfill
Pacific Missile Range, Point Mugu	1.0	Pri	
Naval Construction Battalion Center Port Hueneme	0.2	Pri	
Camarillo Sanitary District	1.54	Sec	Soil conditioner
Camarillo State Hospital	1.0		
City of Santa Paula	1.3	Sec	Soil conditioner
Saticoy Sanitary District	0.11	Pri	
City of Fillmore	0.51	Sec	Soil conditioner
Los Angeles City Department of Recreation and Parks, Saugus Rehabilitation Center	0.02	Sec	
Los Angeles County Hospital Department	0.028	Sec	
Los Angeles County Mechanical Department, Munz-Mendenhall Camp	0.014	Sec	

TABLE 45 (cont.)

Santa Clara River Basin Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
Los Angeles County Mechanical Department, Wayside Honor Rancho	0.7	Sec	
Los Angeles County Sanitation District	2.4	Sec	
Los Angeles County Sanitation District	0.6	Sec	
Simi Valley Unified School District, Knolls School	0.019	Sec	
Moorpark County Sanitation District	0.31		
City of Thousand Oaks (Hill Canyon Plant)	5.0	Sec	Fertilizer
City of Thousand Oaks (Olsen Road Plant)	0.08	Sec	Landfill
Sanitation, Inc.	2.5	Sec	Disposed of to Agricultural Land
Ventura County Sheriff's Dept. Valley Station	0.002		
Los Angeles County Hospital Department Antelope Valley Rehabilitation Center	0.034	Sec	
Los Angeles River Basin			
Los Angeles County Engineer (Malibu Canyon Plant)	0.004	Ter	To Hyperion
Las Virgenes Municipal Water District Tapia Plant	1.6	Sec	Landfill
L.A. County Engineer Miller Kirkpatrick Camp	0.04	Pri	Spread on Land

TABLE 45 (cont.)

Los Angeles River Basin

Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
Los Angeles County Engineer Trancas Canyon Plant	0.05	Pri	To Hyperion
Los Angeles County Mechanical Department Encinal Canyon Plant	0.01	Pri	Land
Los Angeles County Engineer Lechuza Point Plant	0.001	Sec	To Hyperion
Joint Water Pollution Control Plant (JUPCP) - County Sanitation Districts of Los Angeles County	370	Pri	Fertilizer and Ocean
City of Los Angeles Hyperion Plant	340 85	Pri Sec	Ocean
City of Los Angeles Terminal Island Plant	8	Pri	Landfill
City of Los Angeles Valley Settling Basin	0.6	Sec	To Hyperion
County Sanitation District of Los Angeles County (Los Coyotes Water Reclamation)	95	Sec	To JWPCP
County Sanitation District, Los Angeles County Whittier Narrows	15.2	Sec	To JWPCP
City of Los Angeles Griffith Park Zoo	1.5	Pri	To Hyperion
City of Burbank, Department of Public Works	5.2	Sec	To Hyperion
Las Virgenes Municipal Water District Mulwood Plant	0.27	Sec	Landfill
Los Angeles County Mechanical Department Camp Holton	0.015	Pri	Landfill

TABLE 45 (cont.)

Los Angeles River Basin Plant Name	Effluent (MGD)	Degree of Treatment	Sludge Disposal Method
Crescenta Valley County Water District, Lauterman Plant	0.030	Septic Tank	To Hyperion
Crescenta Valley County Water District, Wiley Plant	0.112	Sec	To Hyperion
Los Angeles County Sanitation District #28	0.17	Sec	Landfill
Los Angeles County Sanitation District #22	0.7	Sec	To JWPCP
Los Angeles County Mechanical Department, Barley Flat Camp	0.01	Sec	Landfill
Los Angeles County Mechanical Department, Tonbark Flat Camp	0.012	(To be rebuilt)	
Los Angeles County Sanitation District #21 Pomona Water Reclamation Plant	10.0	Sec	To JWPCP
Los Angeles County Mechanical Department, Paige Afflerbaugh Camp			

To obtain these goals the Boards adopted twelve general principles and a number of others concerning discharges to various types of water. The following are the general principles:[302, 303]

A) No current or proposed program which includes waste disposal to an aquatic environment shall be considered an unchangeable solution.

B) The Board shall be aware at all times of the effects on the total environment: water - land - air.

C) All water quality management systems throughout this region shall provide for maximum waste water reclamation and reuse and shall consider discharge of wastes to the aquatic environment only when wastewater reclamation is precluded by processing costs or lack of need for reusable water.

D) The number of independent treatment facilities shall be minimized, and plans shall direct these consolidated systems to maximize their capacities for waste water reclamation, assure efficient management of wastes, and meet potential demands for reclaimed water.

E) Waste water reclamation, waste discharges, and ground water basin replenishment with imported waters will be considered with maximum emphasis on protection and enhancement of ground water quality.

F) Existing and future discharge pipelines extending into tidal waters shall be ultimately used to provide only failsafe protection against the breakdown of reclamation systems, to discharge excess water beyond the market for reclaimed water, or to provide for interim disposal during development of a market for reclaimed water.

G) Land use practices, including agricultural practices, must assure protection of beneficial water uses and the aquatic environment.

H) Promote rapid development of treatment and discharge systems to provide for failsafe protection of beneficial uses and the aquatic environment during the interim period leading to maximum reuse of freshwaters.

I) Source control and pretreatment to minimize toxicants and biostimulants will be required.

J) Dumping from vessels in the open ocean and coastal waters, by any person subject to the jurisdiction of the State, and which may affect the quality of said waters, shall not constitute a satisfactory permanent plan for the disposal of wastes. This shall be phased out as rapidly as possible.

K) Where reliable values are available, numerical limitations on constituents in effluents will be used in discharge requirements. Where these are not available, studies must be made to develop them.

L) The transport of hazardous materials shall be conducted in such a manner to fully safeguard beneficial uses from the effects of accidental spillage, or leakage.

Since the goals state that beneficial uses and aquatic environments are to be protected and that reclamation and reuse of waste water is to be at the maximum practical level, certain substances must not be present in sewage treatment plant influent. Therefore, industrial wastes which contain these substances must be pretreated where source control cannot be achieved. The following are the principles under which this source control or pretreatment should take place:

A) Industrial and municipal effluents shall be so treated as to assure essentially complete removal of the following substances·

Chlorinated hydrocarbons
Toxic substances
Harmful substances that may enter food webs
Excessive heat
Radioactive substances
Grease, oil, and phenolic compounds
Excessively acidic and basic substances
Heavy metals such as lead, copper, zinc, mercury,
  or mercury compounds.
Other deleterious substances.

B) Sewering entities are encouraged to implement comprehensive regulations to prohibit the discharge to the sewer system of substances listed in paragraph "A" which may be controlled at their source.

C) Sewering entities are encouraged to implement comprehensive industrial waste ordinances to control the quantity and quality of organic compounds, suspended and settleable substances, dissolved solids, and all other materials which may result in overloading of the municipal waste treatment facility.

D) Applicants for State and Federal grants for construction of waste treatment facilities shall be required to submit proof of implementation of adequate source control and industrial waste ordinances.

The following are the principles for the discharge of effluents to various types of water. The first set applies to tidal waters:

1) The quality of all tidal waters of this region shall be such as to permit maximum recreational use where such use is practicable.

2) Natural water quality shall be maintained in coastal areas within a line 1,000 feet from the mean low water line or to the depth of 18 feet, whichever is the greater, and within all areas of special significance.

3) There shall be no effluents discharged into areas which possess unique or uncommon cultural, scenic, aesthetic, historical, or scientific values. Such areas shall be designated in water quality control plans adopted by the Regional Board or designated by the State Board after consideration of recommendations by the Regional Board and public hearing.

4) Effluents discharged to tidal waters shall contain no materials which are hazardous to human life or harmful to aquatic life as a result of accumulation in the environment or the food webs.

5) Effluents of quality suitable for disposal shall be discharged into deep areas below established thermoclines through diffusion systems designed to disperse waste constituents and assure against their return to inshore areas in recognizable form.

6) Waste discharge requirements shall take into consideration additive or accumulative effects of adjacent discharges.

7) Effluents containing dissolved salts in excess of concentrations in the receiving water shall be discharged in a manner and at locations and temperatures which will assure the well-being of aquatic organisms.

8) The discharge of residual industrial and municipal effluents will be permitted only after submission of a detailed environmental impact study which conclusively shows that all practical steps have been taken to control the entrance of toxicants into the system, and that the resultant discharge will not adversely affect aquatic environments or beneficial uses of water.

9) The discharge of sewage sludge to tidal waters shall be discontinued at the earliest possible date.

Discharges to bays:

1) All provisions of "Tidal Waters," shall be applicable to bays unless more restrictive provisions are contained within this section.

2) Discharge of effluent to bays shall be discontinued prior to January 1, 1976, unless such effluent is so treated as to assure essentially complete removal of the following:

Suspended, floatable, or settleable material

Objectionable colors, tastes, or odors

Conservative or acute toxicants, or other toxicants in sub-lethal concentrations which may adversely affect marine organisms

Infectious materials and pathogens, including those which may taint or render poisonous fish and shellfish

Radioactive materials

Discharges to estuaries:

1) All provisions of "Tidal Waters," shall be applicable to estuaries unless more restrictive provisions are contained within this section.

2) Discharge of effluent to tidal estuaries shall be discontinued prior to January 1, 1976, unless such effluent is treated so as to assure essentially complete removal of the following:

Suspended, floatable, or settleable material

Objectionable colors, tastes or odors

Conservative or acute toxicants, or other toxicants in sub-lethal concentrations which may adversely affect marine organisms

Infectious materials and pathogens, including those which may taint or render poisonous fish and shellfish

Radioactive materials

Biostimulants that will promote significant growth and reproduction of undesirable or dangerous organisms

Discharges to fresh waters:

1) The discharge of effluents into surface fresh waters shall be discontinued unless it can be demonstrated that the effluent is of a quality which will assure the continued beneficial uses of the receiving waters.

2) Waste treatment and disposal projects should provide for maximum reuse of effluents by irrigation of agricultural lands.

Discharges to ground water:

1) Waste waters percolated into the groundwaters shall be of such quality at the point where they enter the ground so as to assure the continued usability of all ground water of the State.

2) The discharge shall not contain toxic substances in excess of accepted drinking water standards.

3) All taste and odor-producing substances shall be regulated to protect the beneficial uses of the receiving waters.

4) Control of salinity shall be strictly regulated to prevent problems of adverse salt balance.

5) Land discharge systems shall be designed for and be capable of year-round operation.

6) The discharge shall not contain nitrogen or nitrogenous compounds in amounts which could result in nitrate concentration in the ground waters above 45 mg/l.

7) Ground water recharge with high quality water shall be encouraged.

8) Disposal of economically reclaimable waste water by evaporation shall be discouraged.

Implementation Plan for Controls

The major thrust of the implementation plan is toward the minimum number of sewage treatment plants with the maximum amount of water reclamation. The two Regional Boards of the State Water Resources Control Board annually publish a project list of needed sewerage project for each of the succeeding five years. The projects are scheduled according to the following criteria:[302, 303]

A) Those needed to correct existing water quality or water pollution problems or to conform to an area-wide sewage collection plan will be scheduled at the earliest practicable date.

B) Projects affecting a common receiving water or that can be logically included in an areawide or consolidated system will be scheduled as close together in time as water quality needs permit.

C) Treatment plants nearing flow or treatment design capacity will be scheduled so the expanded facilities will be available before a problem develops.

D) Water reclamation projects which beneficially improve water quality and which conserve water resources through feasible reuse will be scheduled as soon as practicable.

E) Not foregoing any of the above criteria, projects will be scheduled for a uniform level of construction for each fiscal year within the five-year period.

In order to achieve effective water quality management, three categories of water quality monitoring are required. First, to insure that optimum treatment efficiencies and compliance with waste discharge requirement are obtained, monitoring of individual treatment plants is necessary. Second, to insure that the state water quality criteria are met and maintained, the receiving waters must be monitored. Third, the effects on water quality of re-routing the state's waters through water resource development projects must be determined. Within the region there are more than 150 monitoring sites including the on-site monitoring of individual sewage treatment plants. Readings at the former sites are taken for various pollutants on a time table which varies from semi-monthly for some pollutants, to annually for others.[302, 303]

Intermedia Alternatives

Sludge disposal represents the most obvious transfer from the water to an alternate medium. Since there is very little free fresh surface water in the region, and the little that does exist is either in small mountain streams or in artificial lakes serving as the metropolitan water supply, there is practically nothing suitable for waste water discharge. Therefore, practically all municipal and industrial waste water is discharged to sewer systems.[302] At the present time, between 50 and 65 percent of the sludge generated in the region is disposed to the land, either in landfills or as soil conditioner or fertilizer. The majority of the remainder is presently disposed of by the City of Los Angeles Hyperion plant through an ocean outfall. The City has been ordered by the Environmental Protection Agency and the State Water Resources Control Board to eliminate this ocean discharge of sludge. The City was required to present a program, by July 1972, to achieve this end and to implement the program by January 1974.[306] Because of the strict emissions standards for air discharges, incineration of the sludge was immediately discontinued. Since no manufacturer of incineration equipment produces a unit capable of incinerating sludge within the established emission limits, the only available medium for discharge is the land. The City has proposed two alternatives for land disposal, either sanitary landfills or spreading on the land as a soil conditioner and fertilizer.[306]

The City eliminated a third alternative of mixing digested sewage sludge with refuse in sanitray landfills as impractical. This alternative is further explored in the evaluation below the data base for some of the City's assumptions seem to be incomplete. The reason this alternative was eliminated by the City was an estimated lack of solid refuse with which to mix the sludge. The City's calculations are summarized below: 306

(a) Gallons of liquid/ton of refuse to reach full capacity = 134.5 gal/ton

(b) Gallons of 4 percent slurry produced by Hyperion Plant per/day = 1,200,000 gal

(c) Tons refuse required for mixing (b ÷ a) = 8900 tons/day

(d) Refuse collected by City sanitation and street maintenance = 4960 tons/day

(e) Ratio of required refuse to available refuse (b ÷ c) = 1.8

The conclusion therefore was that this alternative is not feasible. There are, however, some other considerations. Recent investigations in the City of Oceanside, California, indicates a load factor of 0.5 to 1.5 pounds of slurry per pound of solid waste.[226] The ratio used by the City, 134.5 gal/ton, is approximately 1120 lbs/ton or a load factor of 0.56. Since the field capacity of refuse comes from 0.5 to 1.5 depending on its composition, this is a properly conservative figure. In 1970 only 810,000 gal per day of 4 percent slurry was generated rather than 1,200,000 gallons/day. In that same year the refuse collection was much higher than the 1,800,000 tons estimated, since this amount includes only the refuse collected by the sanitation and street maintenance departments, i.e., the domestic refuse, and omits the commercial refuse collected by private haulers. The latter probably equalled the amount of the former, since the estimated 1.8 million tons amounts to only 3.5 pounds per capita day for the City's 2.8 million inhabitants. The total solid waste generated in Los Angeles County is 7.5 pounds per capita day.[322] Even if this ratio is no higher in the City than in the County, the total produced in the City would be about 3.8 million tons of refuse. Therefore it seems that mixing digested sludge with refuse is a feasible alternative at present. A separate projection of solid waste generation should be made to compare with anticipated future sludge generation. This alternative is the least costly and would result in no significant increase in landfill acreage needed. The 4 percent slurry would aid in the compaction and stabilization of the solid waste. The recent investigations indicate that no significant leaching or other intermedia transfer would result if the mixing is carried out in properly designed and operated landfills, and if there would be no direct contact with underground water flows.[306]

The disposal of sludge cake in sanitary landfills (the first alternative) would create 642 cubic yards of sludge cake per day for 1970 sewage volumes. This would increase to 1130 cubic yards per day in the year 2000.[306] Dewatering the sludge by vacuum filters would cost an estimated $907,700 annually or $12.40 per dry ton. Alternate dewatering systems are centrifugation (annual cost $1,123,000 or $15.40 per dry ton) and sludge drying beds ($45 per dry ton).[306] The addition of this sludge cake to sanitary landfills would not result in a significant increase in landfill volume required, as the slurry would tend to be absorbed and to fill in the voids in the refuse. Two methods of carrying out this alternative are to dry the sludge at the Hyperion plant and transport it by truck to the landfills, or to transport the liquid sludge by pipeline or railway to a landfill site and then dewater it. Tables 46 and 47 show transportation times and costs for these alternatives. In properly managed landfills, this alternative would properly result in no significant leaching or runoff problems.

Agricultural spreading, according to the study made by the City, would require 6,100 acres to spread the sludge if the treatment plant effluent were used as a carrier after denitrification. Without denitrification, this same study indicates 31,000 acres would be required because of a limitation on the nitrogen application to the land. Research by

Ralph Stone and Company indicates that this limitation is not so severe, and that less land would thus be needed. Using only the transported 4 percent slurry the land requirement would be 10,500 acres. The City chose to evaluate the 6,100 acre alternative with denitrification of the sewage plant effluent and mixture with the sludge. They chose to evaluate transporting it to a city owned farm in the Lancaster - Palmdale area and the importation of 33 million gallons per day of dimitrified effluent for the 6,100 acres in order to be able to utilize 1.4 million gallons per day of 4 percent slurry. The cost of transporting this water makes this alternative prohibitive, and the City rejected this alternative. These high costs seem to be created by the method chosen for the Agricultural Plan-- an assumed City-owned farm in a water deficient area. An in-depth study should be made of the possibility of transporting the slurry to various agricultural areas for mixing with irrigation water by agreement with local farmers participating in a program with the City.

Three methods of transportation of the sludge to the final disposal site have been investigated. These methods are truck, pipeline and railroad. For economical trucking, the sludge must be dewatered to a cake of 75 percent moisture, and a slurry of 4 percent and 8 percent solid content for pipeline and railroad, respectively.

Table 46 shows the distances and travel time to various sanitary landfills which were evaluated as disposal sites for the sludge. The cost for disposal to one landfill site is shown in comparison to other transportation methods and disposal sites in Table 47.

TABLE 46 306

Disposal Site	Site Classification	Round Trip Distance	Round Trip Time
1 - Mission Sepulveda	Class II	40 miles	1 hr. - 44 min.
2 - Calabasas	Class I	61 miles	2 hrs. - 43 min.
3 - Puente Hills	Class II	62 miles	2 hrs. - 50 min.
4 - Palos Verdes	Class I	28 miles	1 hr. - 16 min.
5 - Lopez Canyon	Class II	69 miles	3 hrs. - 5 min.

The piping of sludge could take place in two ways. The proposed site would be the Lancaster-Palmdale area, and the pumping of the sludge would be accomplished in either of two ways. In one, only the sludge solids and the water necessary for transport would be pumped; in the other, an agricultural facility is assumed at the end of the pipeline which would require more water than is either available in the Antelope Valley area or from the transport of the sludge. This remaining need of 33 mgd would have to be supplied from the Los Angeles Basin and would require a larger pipeline and more pumping stations.

TABLE 47

COST SUMMARY OF LONG TERM SLUDGE DISPOSAL ALTERNATIVES

ALTERNATIVES	Capital Costs	O & M Costs	PRESENT WORTH IN DOLLARS Total Costs	PRESENT WORTH IN DOLLARS Equivalent Annual Cost	Cost Per Dry Ton[1]
Truck to Mission Sepulveda Sanitary Landfill:					
Trucking Operation-1975 (9 units) 2000 (13 units)	1,576,000	13,201,000[2]	14,776,000	1,156,000	15.83
Dewatering Operation	3,012,000	9,684,000	12,696,000	993,000	13.61
Total Operation	4,587,000	22,885,000	27,472,000	2,149,000	29.44
Pump to Lancaster-Palmdale Area for Agricultural Use (6100 Acres) (includes water)	47,322,000	53,375,000	100,697,000	78,800,000	108.00[3]
Pump to Lopez Canyon Sanitary Landfill	8,109,000	15,501,000	23,610,000	1,847,000	25.30[4]
Pump to Lancaster-Palmdale	15,746,000	2,852,000	18,598,000	1,455,000	19.93
Rail to any of the following disposal sites (40 to 80 tank cars):					

a) Bakersfield
b) Boron
c) Eagle Mountain
d) Coachella Valley
e) Edwards Air Force Base

1. Average of approximately 200 Dry Tons/Day between 1975 and the year 2000.
2. Includes Disposal Fee costs.
3. Includes the net cost of pumping 30 mgd of irrigation waters, excluding potential income from the sale of water and agricultural products, and does not include the purchase of land.
4. Includes dewatering facilities at the disposal site.

Six sites were evaluated to receive sewage sludge via railroad. These are shown in Table 47. The sludge is intended to be used for agricultural purposes at El Centro, Coachella Valley, Edwards Air Force Base, and Bakersfield. At the remaining two sites, Boron and Eagle Mountain, the sludge is considered to be used for land reclamation at past sites of mining activities by the Borax Company and the Kaiser Steel Company.[306]

This firm has recently completed a feasibility study dealing with sewage sludge handling and disposal for the Ventura Regional County Sanitation District. The basic conclusions are that, at the present time, disposal to Class I sanitary landfills offers the best, most economical solution to the sludge disposal problems. The Oxnard plant is building an incinerator for its sludge; however, on the whole it is felt that landfill and, to a lesser degree, agricultural uses and land reclamation are more economically and ecologically sound. Several plants in Ventura County stockpile dried sludge and allow farmers and commercial users to haul it away, thereby saving the cost of transportation and final disposal.[307] The costs of disposal of sewage sludge vary according to which of two systems (a combined regional system or individual plants), two methods of transportation (truck and pipeline), and two final disposal methods (landfill and agricultural land) is employed. The costs per dry ton of sewage sludge are given in Table 48.[307]

Impacts of Intermedia Transfer

The disposal of dewatered sewage sludge in a sanitary landfill differs to some extent from ordinary dry refuse disposal in that sludge contains a moisture content of about 75 percent, biodegradable organic material, and possibly heavy metals and chlorinated hydrocarbons. These factors, as well as others, must be considered when evaluating the environmental effects of digested sludge disposal to landfill. Care must be taken to insure that contiguous areas, groundwater, and the atmosphere are not degraded by movement of moisture although this is also true for ordinary landfills. The long term plan will include landfill, land reclamation, and agricultural soil conditioning. A complete environmental impact statement will be needed to determine the effect of these proposals.[306]

The Ventura County sludge disposal study[307] also mentions the leachate problem and the danger of disease carried flies and rodents. The report recommends that the sludge be covered daily with 6 inches of earth to reduce this risk. Also, it is reported that pathogens are not found at depths of greater than 7 feet in soil; if the ground water is below this level there is little danger of pathogenic contamination. However, other types of pollutants, such as heavy metals, can percolate to greater depths.[307]

Another environmental trade-off which must be considered concerns the method of transportation of the sludge to the disposal site. The use of trucks, even under the strict 1975 emission standards, produces more than 17 times the air pollution of a natural gas fired power plant producing the power to pump the sludge. However, the truck pollution is distributed over the length of the trip (4 to 20 miles), while the power plant is a point source.[307] The trade-off considerations are shown in Table 49.

TABLE 48 [307]

COST OF VARIOUS TRANSPORTATION AND DISPOSAL METHODS

Alternate 1 - Combined System

	Dollars/dry ton sludge solids	
	Pipeline	Truck (10,000 gal)
Landfill	8.38	12.53/
Agricultural Land	3.60/	6.15/

Alternative 2 - Individual System

	Pipeline	Truck (10,000 gal)
Landfill		
Simi Valley	12.36	
Thousand Oaks	27.94	
Camarillo	60.37	9.92
Fillmore	304.21	
Santa Paula	97.63	
Oxnard	35.68	13.17
Oak View	91.75	14.20
Ventura	18.91	

Agricultural land under Alternative 2 is not feasible due to high costs.

TABLE 49

ENERGY RELATED POLLUTION FOR SLUDGE TRANSPORTATION

Air pollutant	Source quantity, lbs/yr Truck haul No controls	 1975 controls[*]	 Energy for pumping in pipeline
Hydrocarbons	590	59	4
Nitrogen oxides	3,650	365	39
Sulfur oxides	250	25	neg
Carbon monoxide	3,100	310	neg
Particulates	230	23	2
Totals	7,820[+]	782[+]	45[+]

[*] 1975 standards require 90 percent reductions.

[+] For transporting 9,350 tons of dry solids based on 1975 quantities.

IMPACTS OF AIR AND WATER POLLUTION CONTROL ON SOLID WASTE MANAGEMENT

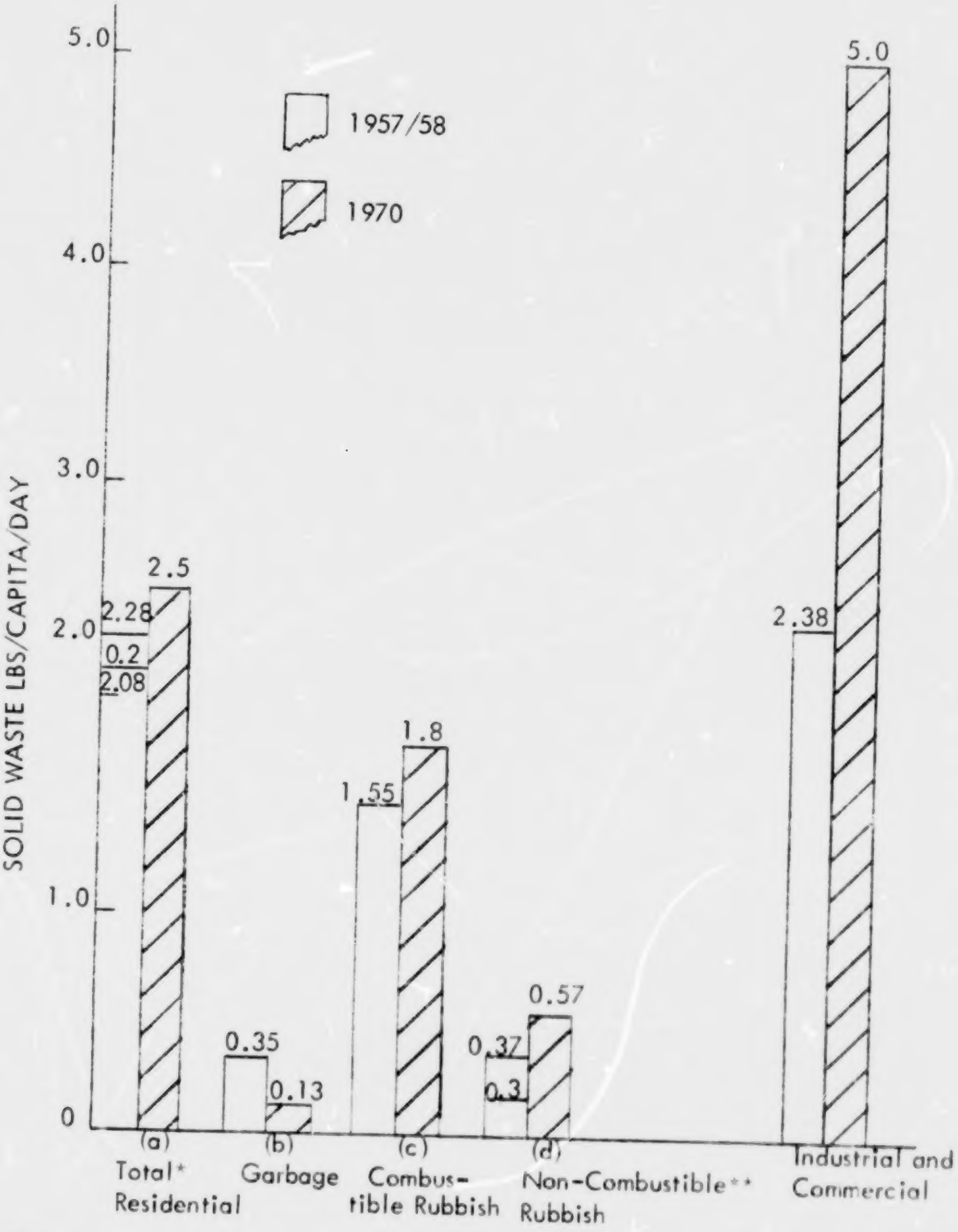
Most current methods of controlling air and water pollution create residues in solid form and the impact of these controls on the quantities of solid waste generated in the region is significant. In recent years, the solid waste collected in the region has increased sharply, especially the wastes from commercial and industrial sources. Figure 28 presents the pounds per capita per day of various categories of solid wastes collected in the City of Los Angeles in 1957/58 and in 1970. Total residential solid wastes increased from 2.28 pounds to 2.5 pounds per capita per day.[330,322] A decline per capita amounts of garbage collected was offset by increases in combustible and noncombustible rubbish. It should be pointed out that this time span occurred after backyard burning was prohibited in 1957, so that the 1957-58 figures for domestic refuse already include the increase caused by the law.[330] Industrial and commercial wastes collected increased from 2.38 pounds per capita day in 1957-58 to 5.0 pounds per capita day in 1970.[330, 322] During this period industrial incineration has been slowly phased out, and stricter air pollution controls are producing more solid residues.

Figure 29 illustrates the intermedia alternatives for solid waste management. Incineration and recycling, two methods which reduce residues disposed to the land, have been mostly eliminated in recent years. Previously the City collected tin and glass products separately, but this is no longer true. Garbage grinders, which transfer solids to the water,are increasingly popular.

Recent decisions by the EPA and the State of California will require the City of Los Angeles to discontinue the discharge of sewage sludge to the ocean. This will result in increased amounts deposited in landfill sites or spread on agricultural land. This will not be an unmanageable burden on the landfill sites (see discussion of intermedia alternatives in Intermedia Water Pollutants in Section IX, the Regional Case Study). Approximately 10,000 tons per day of solid waste are collected in the City of Los Angeles, while only 200 tons per day of dry solids would be generated for disposal by the Hyperion plant.[306] Since municipal solid wastes are about 20 percent water[322] based on wet weight, the increase in solids disposed to landfills will only be about

$$\frac{\text{200 dry tons/day from sewage plant}}{\text{10,000 wet tons collected in City} \times 0.80\ \frac{\text{dry wt}}{\text{wet wt}}} = 2.5\ \%$$

No volume increase would be anticipated based on recent research investigations.[322] Air pollution controls, however, generate a very significant increase in solid wastes. Figure 30 illustrates the impact by showing what the effect would be of a return to post incineration practices for solid wastes collected in Los Angeles. Previous to 1957-58 about 60 percent of combustible rubbish was burned and left 10 percent of the burned material as ash. If this were done today, it would result in a clear case of 0.97 pounds/capita day in residential solid waste,and would reduce the amount collected from 2.5 pounds to 1.53 pounds per capita day. About 50 percent of industrial and commercial rubbish was previously burned, and left 10 percent of the burned



NOTE: a = b + c + d

*1957/58 includes 2.08 lb/capita/day + 0.2 lbs/capita/day recycled tin and glass. No recycling in 1970.

**1957/58 includes 0.2 lb/capita/day recycled tin and glass plus ashes. No separation of tin and glass in 1970.

FIGURE 28
LBS PER CAPITA SOLID
WASTE GENERATION
CITY OF LOS ANGELES

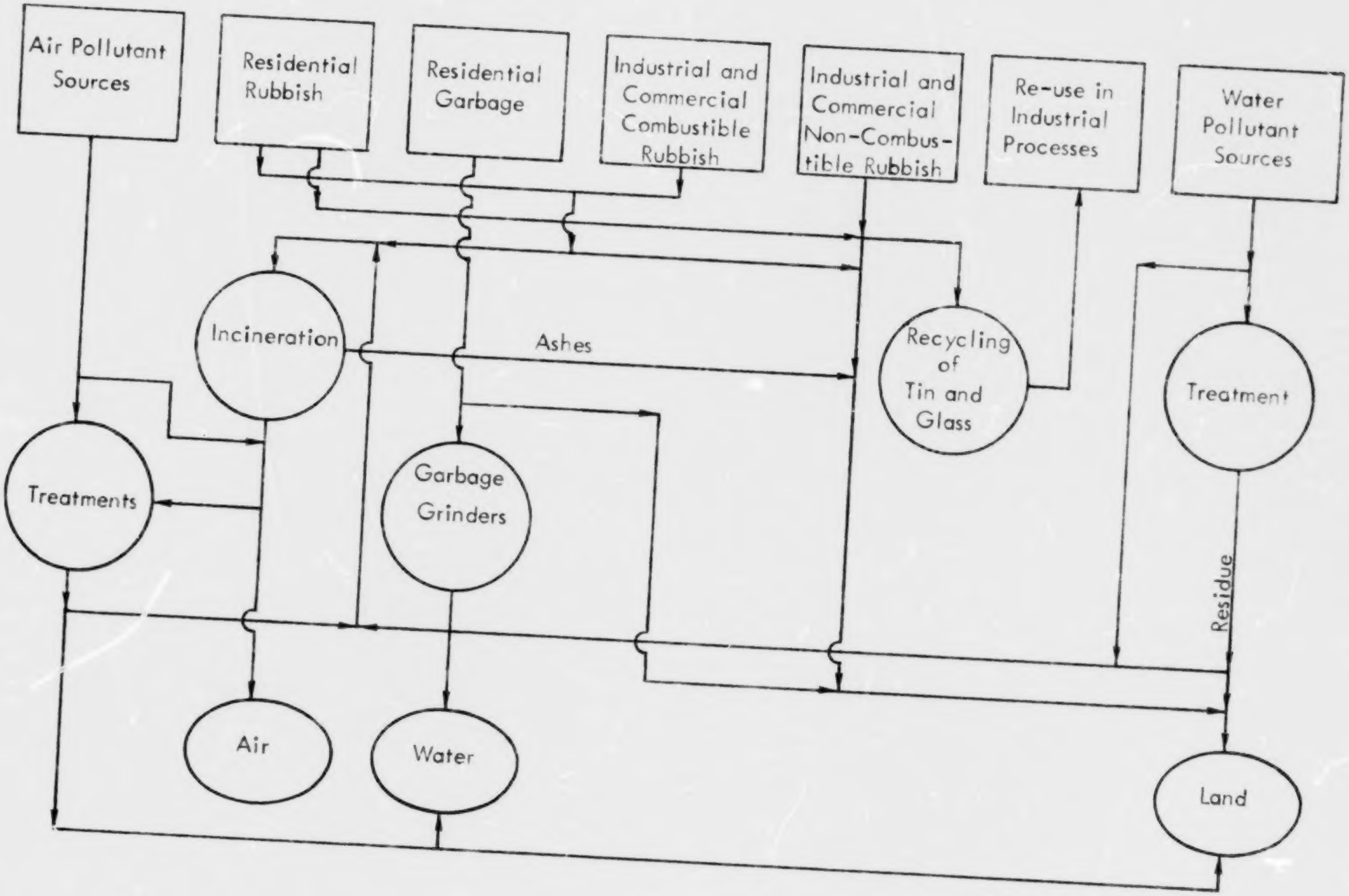
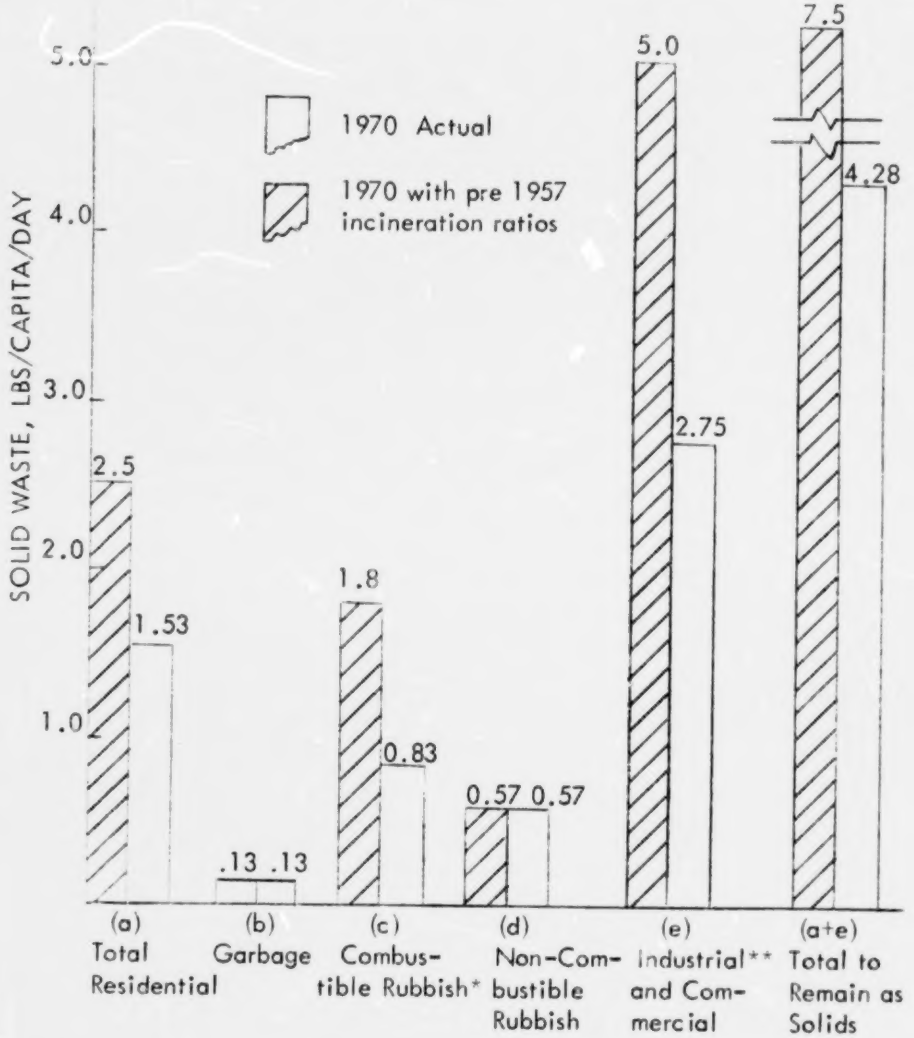

Air Pollutant Sources
Residential Rubbish
Residential Garbage
Industrial and Commercial Combustible Rubbish
Industrial and Commercial Non-Combustible Rubbish
Re-use in Industrial Processes
Water Pollutant Sources
Incineration
Ashes
Recycling of Tin and Glass
Treatment
Treatments
Garbage Grinders
Residue
Air
Water
Land

FIGURE 29
IMPACT OF SOLID WASTE
HANDLING PROCEDURES ON INTERMEDIA
MANAGEMENT



NOTE: a = b + c + d

* 60 percent incineration and 10 percent of volume disposed as ash.

**50 percent incineration and 10 percent of volume disposed as ash.

FIGURE 30
IMPACT OF NON-INCINERATION
ON SOLID WASTE DISPOSAL
TO LANDFILLS IN LOS ANGELES

material as ash. If this were done today, it would result in a decrease of 2.25 pounds per capita day in commercial and industrial solid wastes, and would reduce the amount collected from 5.0 pounds to 2.75 pounds per capita day. The combined input of a return to residential, commercial, and industrial burning would reduce solid wastes in Los Angeles from 7.5 pounds to 4.28 pounds per capita day, a 43 percent reduction. It is difficult to specify how much of the 2.62 pounds per capita day increase in industrial and commercial solid wastes, shown in Figure 28, is the result of the elimination of industrial incinerators and how much is the result of more stringent pollution controls on industrial processes.

SECTION X
ACKNOWLEDGMENTS

Sincere appreciation is expressed for the able direction and assistance given to us by The Environmental Protection Agency's Project Officer, Dr. Roger Shull. We also wish to express our thanks to the Los Angeles Air Pollution Control District and the Southern California Association of Governments for their close cooperation and valued help in providing the needed data for the regional study.

SECTION XI

REFERENCES

1. Kleiber, M., The Fire of Life, John Wiley and Sons, Inc., New York (1961).

2. Private Communication, Roger Shull , Environmental Protection Agency, Washington, D.C.

3. Stokinger, H.E., Coffin, D.L., "Biologic Effects of Air Pollution," in Air Pollution, Volume I, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

4. Gross, P., "The Processes Involved in the Biologic Aspects of Pulmonary Deposition, Clearance, and Retention of Insoluble Aerosols," Health Physics, 10, p 975 (1964).

5. Dixon, J.P., Air Conservation, Air Conservation Commission, AAAS, Washington, D.C. (1965).

6. "Committee on Air Pollution Report," Beaver, H., Chairman, H.M. Stationery Office, London.

7. Robinson, E., in Air Pollution, Volume I, 2nd ed., Stern, A. C., ed., Academic Press, New York (1968).

8. NCA Fuel Engineering Data, National Coal Association, Washington, D.C. (1961).

9. American Public Works Association, Water Pollution Aspects of Urban Runoff, Federal Water Pollution Control Administration, Washington, D.C. (1969).

10. Selusta, W., "Ferrous Metallurgical Processes," in Air Pollution, Volume III, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

11. Corn, M., "Nonviable Particles in the Air," in Air Pollution, Volume I, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

12. Frankel, R.J., "Technologic and Economic Interrelationships Among Gaseous, Liquid, and Solid Waste in the Coal Energy Industry," WPCF JOURNAL, 40, p 779 (1968).

13. Vandergrift, A. E., et. al., "Particulate Pollution in the United States," APCA JOURNAL,21, No. 6, pp 233-235 (1970).

14. Council on Environmental Quality, Environmental Quality, Third Annual Report, (1972).

15. Garhill, J.E., "Waste Pollution Potential of Air Pollution Control Devices," in Air Pollution, Volume III, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

16. United States Department of Health, Education, and Welfare, Control Techniques for Particulate Air Pollutants, NAPCA Publication No. AP-51.

17. Stephen, D.G., "Dust Collector Review," Transactions Foundryman's Soc., 68, p 1 (1960).

18. Magill, P.L., Holden, F.R., and Achley, C., Air Pollution Handbook, McGraw Hill, New York (1956).

19. NCA Fuel Engineering Data, National Coal Association, Washington, D.C. (1961).

20. Jackson, R., Survey of the Art of Cleaning Flue Gases, British Coal Utilization Research Association, Leatherhead-Surry, England (1959).

21. Texas Cotton Ginners Association, What We Know About Air Pollution Control, Special Bulletin No.1, Dallas, Texas (1965).

22. Danielson, J.A., ed., Air Pollution Engineering Manual, U.S. Department of Health, Education, and Welfare, National Center for Air Pollution Control, Cincinnati, Ohio, PHS Publication No. 999-AP-40 (1967).

23. American Petroleum Institute, Engineering Department, Cyclone Dust Collectors, New York (1955).

24. "Efficiency Application and Selection of Collectors," in Air Pollution, Volume I, 2nd ed., Stern, A. C., ed., Academic Press, New York (1968).

25. Anonymous, "Plugging $8,600 Leak," Chemical Proc., June (1967).

26. Spraying Systems Co., Pollution Abatement Manual, Spraying Nozzles and Accessories, Bellwood, Illinois (1966).

27. Buffalo Forge Co., Hydraulic Scrubbing Towers, Bulletin AP-525a, Buffalo, New York (1957).

28. Teller, A.J., "Crossflow Scrubbing Process," U.S.Patent No. 3, 324, 630, June 13, 1967.

29. National Dust Collector Corp., *Hydro Filter*, Bulletin N-20, Skokie, Illinois.

30. Rice, O.R., and Bigelow, C.G., "Disintegrators for Fine Cleaning Blast Furnace Gas," *Amer. Inst. of Mining and Metall. Eng.*, Feb. (1950).

31. Rickles, R.W., "Waste Recovery and Pollution Abatement," *Chem. Eng., 133*, (1965).

32. Zhevnovatyi, "The Influence of the Basic Parameters of Hydrocyclone Thickness on Their Operating Efficiency," *Ind. Chem. Eng., 2,* p 580 (1962).

33. Busch, A.W., "Liquid-Waste Disposal System Design," *Chem. Eng.*, p 83 (1965).

34. Brooke, M., "Corrosion Inhibitor Checklist," *Chem. Eng.,* p 134 (1962).

35. Jacob, H.L., "In Waste Treatment, Know Your Chemicals, Save Money," *Chem. Eng.,* p 87 (1960).

36. Dickerson, B.W., and Brooks, R.M., "Neutralization of Acid Wastes," *Ind., Chem. Eng., 42*, p 599 (1950).

37. American Petroleum Institute, *Manual on Disposal of Refinery Wastes, Volume III,* Division of Refining, New York (1960).

38. American Petroleum Institute, *Manual on Disposal of Refinery Wastes, Volume II,* Division of Refining, New York (1957).

39. American Petroleum Institute, *Manual on Disposal of Refinery Wastes, Volume VI,* Division of Refining, New York (1963).

40. Warner, D.L., "Deep-well Disposal of Industrial Wastes," *Chem. Eng., 72*, p 73 (1965).

41. Betz, W.H., and Betz, L.D., *Handbook of Industrial Water Conditioning, 4th ed.*, W.H. Betz and L.D. Betz Co., Philadelphia, Pa. (1953).

42. Anonymous, *Air Pollution Control Equipment,* Ceilcote Co. Bulletin 12-1, Burea, Ohio (1967).

43. Jackson, R., and Waple, E.R., "The Elimination of Dust and Drizzle for Quenching Towers," *Gas World, 75*, May 7, 1968.

44. Frankel, R.J., "Problems of Meeting Multiple Air Quality Objectives for Coal-fired Utility Boilers," *APCA JOURNAL, 19* (1969).

45. Bay Area Air Pollution Control District, "Air Pollution in the Bay Area, Technical Report and Appraisals," San Francisco (1962).

46. Kreschelt, T.E., Kemnity, D.A., and Cuffe, S.T., Atmospheric Emissions for the Manufacture of Portland Cement, U.S. Department of Health, Education, and Welfare, Public Health Service, Cincinnati, Ohio, PHS Publication 999-AP4 (1963).

47. U.S. Department of Health, Education, and Welfare, Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, Public Health Service, Cincinnati, Ohio, PHS Publication 999-AP-13 (1965).

48. Licht, W., "Removal of Particulate Matter from Gaseous Waste-filtration," University of Cincinnati, Ohio, (for the American Petroleum Institute, New York) (1961).

49. Simon, H., Air Pollution Control Manual, Ch.4, Sect. C, County of Los Angeles APCD, (1964).

50. Frederick, E.R., "How Dust Filter Selection Depends Upon Electrostatics," Chem. Eng., 68, p 107 (1961).

51. Silverman, L., "Technical Aspects of High Temperature Gas Cleaning for Street Making Processes," Air Repair, 4, p 189 (1956).

52. Kreschelt, T.E., Kemnity, D.A., and Cuffe, S.T., Atmospheric Emissions from the Manufacture of Portland Cement, U.S. Department of Health, Education, and Welfare, National Center for Air Pollution Control, Cincinnati, Ohio, PHS Publication 999-AP-17 (1967).

53. Herrick, R.A., Olsen, J.W., Ray, J.A., "Oxygen-lanced Open Hearth Furnace Cleaning with a Glass Fabric Baghouse," APCA JOURNAL, 16, p7 (1966).

54. Friedrick, H.E., "Primer on Fabric Dust Collection," Air Eng., 9 p 28 (1967).

55. Noland, R., "Technological Developments in Plant and Equipment Design for Air Pollution Controls," Proceedings of the National Symposium on Air Pollution, Washington, D.C., Jan 11-12, 1967.

56. Dragin, I., "Carbon Black," APCA JOURNAL, 18, p 216 (1968).

57. Clark, J.W., Viessman, W., and Hammer, M.J., Water Supply and Pollution Control, 2d ed., International Textbook Co., (1971).

58. Heinar, H., "Effects on Human Health," in Air Pollution, WHO Monograph No. 46, Geneva (1961).

59. Goldsmith, J.R., "Effects of Air Pollution on Human Health," in *Air Pollution, Volume I, 2d ed.,* Stern, A.C., ed., Academic Press, New York (1968).

60. Dixon, J.P., *Air Conservation*, Air Conservation Commission, AAAS, Washington, D.C. (1965).

61. Bradt, C.L., and Hech, W.W., in *Air Pollution, Volume I, 2d ed.,* Stern, A.C., ed., Academic Press, New York, (1968).

62. Yocum, J.E., "Effects of Air Pollution on Materials," in *Air Pollution*, WHO Monograph No. 46, Geneva (1961).

63. Varney, R., and McCormac, B.M., in *Introduction to the Scientific Study of Atmospheric Pollution*, McCormac, R.B., ed., Reidel, Verdrecht, Holland (1972).

64. Environmental Protection Agency, *Inorganic Chemicals Industry Profile*, Water Pollution Control Research Series (1971).

65. Environmental Protection Agency, *Inorganic Fertilizer and Phosphate Mining Industries: Water Pollution and Control*, Water Pollution Control Research Series (1971).

66. Klein, L., *River Pollution, Causes and Effects*, Butterworths, London (1962).

67. U.S. Public Health Service, *U.S. Public Health Service Drinking Water Standards*, Public Health Reports (1946).

68. World Health Organization, *European Standards for Drinking Water*, Geneva (1961).

69. Daudoroff, P., and Katz, M., "Critical Review of Literature and the Toxicity of Industrial Wastes and Their Components on Fish, Alkalis, Acids and Inorganic Gases," *Sewage Industrial Wastes, 22*, pp 1432-58 (1950).

70. McKee, and Wolf, *Water Quality Criteria*, State Water Quality Control Board, Sacramento, California (1963).

71. Robbins, R.C. and Robinson, E., "Gaseous Pollutants from Urban and Natural Sources," *APCA JOURNAL, 20*, No. 4, pp 233-235 (1970).

72. Haazen-Smit, A.J., "Studies of Air Pollution Control by Southern California Edison Company," *Journal Engineering and Power, 81*, p 1 (1959).

73. U.S. Department of the Interior, *Industrial Waste Profile for a Total Environment, Leather Tanning and Finishing-SIC 3111*, Federal Water Pollution Control Administration, I.W.P. No. 7 (1967).

74. Cadle, R.D., and Magill, P.L., "Chemistry of Contaminated Atmospheres," in Air Pollution Handbook, McGraw-Hill, New York (1956).

75. Middleton, J., Emil, L.O., and Taylor, O.C. APCA JOURNAL, 15, p 476 (1965).

76. Stephens, E.R., Barley, E.J., Taylor, O.C., and Scott, W.E., International Journal Air Water Pollution, 4, p 79 (1961).

77. Ermene, E.D., Chemical Engineering Progress, 53, p 149 (1956).

78. Cyr, J.W., "Study of Dry Caustic vs. Conventional Caustic Peeling and the Effect on Waste Disposal," Proceedings; Second National Symposium on Food Processing Wastes (1971).

79. U.S. Environmental Protection Agency, Agricultural Pollution of the Great Lakes Basin, Water Quality Office.

80. Chass, R.L., Krenz, V.B., Newitt, J.S., and Danielson, O.A., "Los Angeles Acts to Control Emissions of Nitrogen Oxides from Power Plants," APCA JOURNAL, 22, No. 1, pp 15-19 (1972).

81. Eckenfelder, W.W., Water Quality for Practicing Engineers, Barnes and Noble, New York, (1970.)

82. Eliassen, R., and Tchobanoglous, G., "Chemical Processing of Wastewater for Nutrient Removal," Unpublished Data, Stanford University, School of Engineering.

83. Tschobanoglous, G., "Physical and Chemical Processes for Nitrogen Removal: Theory and Application," Unpublished Data, Stanford University, School of Engineering.

84. Alamo Area Council of Governments, Basic Management for Water Reuse, Office of Research and Monitoring, Environmental Protection Agency (1972).

85. Environmental Protection Agency, Wastewater Ammonia Removal by Ion Exchange, Water Pollution Control Research Series (1971).

86. Los Angeles Air Pollution Control District, Summary of Air Pollution Statistics for Los Angeles County, Los Angeles (1963).

87. Haagen-Smit, A.J., and Latham, T.W., Clean Air Quarterly, 8, p 8 (1964).

88. Clayton, G.D., Cook, W.A., and Frederick, W.G., American Ind. Hyg. Assoc. Journal, 21, p.46 (1960).

89. Grut, A., Chronic CO Poisoning, A Study in Occupational Medicine, Zeinksgaard, Copenhagen (1949).

90. Council on Environmental Quality, Environmental Quality, Second Annual Report (1971).

91. Jacobson, W.E., Automotive Emissions, A Technology Assessment Methodology, Volume II, The Mitre Corp., MTR 6009 (1971).

92. Anonymous, "Trends," Pollution Engineering, 4, No. 5, p 13 (1972).

93. Faith, W.L., Air Pollution Control, John Wiley and Sons, Inc., New York (1959).

94. Calvert, S., in Air Pollution, Volume I, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

95. Faith, W.L., Keyes, D.B., and Clark, R.L., Industrial Chemicals, 2d ed., John Wiley and Sons, Inc., New York (1957).

96. Clars, R.L., "The Status of Engineering Knowledge for the Control of Air Pollution," in Proceedings of the National Conference on Air Pollution, United States Public Health Service, Washington, D.C. (1962).

97. U.S. Environmental Protection Agency, "The Clean Air Amendments of 1970 and Air Pollution Aspects of the Food and Agricultural Processing Industry," Proceedings, Second National Symposium on Food Processing Wastes, Water Pollution Control Research Series, 21 (1971).

98. School of Engineering and Applied Science, University of California, Los Angeles, A Methodology for Dealing with Environmental Pollution, Volume II, (1971).

99. Allshuller, A.P., Ortman, G.C., Saltzman, B.E., and Neligan, R.E., APCA JOURNAL, 16, p 87 (1966).

100. Cook, J.W., Hieger, I., Proceedings of the Royal Society, London, Series B, III, p 455 (1932).

101. Dryefuss, J., "U.S. Clean Air Plan Proposes Gasoline Rationing in Southland," Los Angeles Times, Part I, p 26, Dec. 8, 1972.

102. Smith, W.L., and Gruber, C.W., U.S. Public Health Service, Publication 999-AP-24 (1966).

103. Turk, A., in Air Pollution, Volume III, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

104. Paulus, H.J., in Air Pollution, Volume III, 2d ed., Stern, A.C., ed., Academic Press, New York (1968).

105. Rose, A.H., "A Summary Report on Vehicular Emissions and Their Control," report presented to American Society of Mechanical Engineers, New York (1966).

106. California Manufacturer's Association and Los Angeles County Air Pollution Control District, Air Pollution Problems Relating to Organic Solvents, (1965).

107. Robinson, E., and Robbins, R.C., "Gaseous Nitrogen Compound Pollutants from Urban and Natural Sources," APCA JOURNAL, 20, p 303 (1970)

108. Jones, J.R.E., "The Reactions of Fish to Water of Low Oxygen Concentration," Journal of Experimental Biology, 29, p 403 (1952).

109. Lacy, W.J., "The Industrial Water Pollution Control Research and Development Program," National Association of Corrosion Engineers, 26th National Conference, Philadelphia, March 2-6, 1970.

110. U.S. Environmental Protection Agency, Joint Treatment of Municipal Sewage and Pulp Mill Effluents, Water Pollution Control Research Series (1970).

111. U.S. Department of the Interior, The Cost of Clean Water, Volume III, Textile Mill Products, Federal Water Pollution Control Administration (1967).

112. Anonymous, "Treatment Costs," WPCF JOURNAL, 40, No. 9 (1968).

113. Michel, R.L., "Construction Grants and Engineering Branch," Federal Water Quality Act.

114. U.S. Environmental Protection Agency, Characteristics of Waste from Southwestern Cattle Feedlots, Water Pollution Control Research Series (1971).

115. Ralls, J.W., et. al., "Dry Caustic Peeling of Tree Fruit to Reduce Liquid Waste Volume and Strength," in Proceedings, Second National Symposium on Food Processing.

116. Edwin, L.J., and Peniston, A.P., Pollution Abatement and By-Product Recovery in the Shellfish Industry, Water Pollution Control Research Series (1971).

117. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th ed., American Public Health Association, Washington, D.C. (1971).

118. Hoak, R.D., "Physical and Chemical Behavior of Suspended Solids," *Sewage and Industrial Wastes, 31*, p 1401 (1959).

119. Davis, H.C., "Effects of Turbidity Producing Materials in Sea Water on Eggs and Larval of the Clam Venus Mercenaria," *The Biological Bulletin, 118,* No. 1, p 48 (1960).

120. Anonymous, *Report of the Water Pollution Research Board, with the Report of Director of the Water Pollution Research Laboratory for the Year 1960*, Department of Scientific and Industrial Research, H.M. Stationery Office, London, (1961).

121. Seny, W.C., "Removal of Fatty Materials from Edible Fat and Oil Refinery Effluents," in *Proceedings, Second National Symposium on Food Processing Wastes*, Water Pollution Control Research Series (1971).

122. Smith, R., and Eilers, R.G., *Cost to the Consumer for Collection and Treatment of Wastewater*, Advanced Waste Treatment Research Laboratory for Office of Research and Monitoring, Environmental Protection Agency, Water Pollution Control Research Series (1970).

123. Fair, G.M., and Gyer, J.C., *Water Supply and Waste Water Disposal*, John Wiley and Sons, Inc., New York (1967).

124. Barrenscheen, H.K , and Beckh-Widmanstetter, H.A., "Bacterial Reduction of Organic Phosphorus-Containing Acids", *Biochem.Z., 140,* pp 279-283 (1923).

125. Rudakov, K.I., "The Reduction of Mineral Phosphates by Biological Means," *Zbl. Bakt, 70,* pp 202-214, (1927).

126. Luning, O., and Brohm, K., "The Occurrence of Phosphine in Spring Waters," *Z. Untersuch. Lebensmitt, 66*, p 460 (1933).

127. Kerr, R.S., *Characteristics and Pollution Problems of Irrigation Return Flow*, U.S. Department of the Interior, Water Research Center, Ada, Oklahoma (1969).

128. U.S. Environmental Protection Agency, *Role of Animal Wastes in Agricultural Land Runoff*, Water Pollution Control Research Series (1971).

129. Eliassen, R., and Tchobanoglous, G., "Reclamation of Wastewater in the United States," Unpublished Data, Stanford University, School of Engineering.

130. Anonymous, "Mercury-Lamp Pollution: How Much of a Problem," *Electrical World, 175*, No. 4, p 100 (1971).

131. Joensuu, O.I., "Fossil Fuels as a Source of Mercury Pollution," *Science, 172,* pp 1027-1028 (1971).

132. White, D.E., Hinkle M.E., and Barnes, I., "Mercury Contents of Natural Thermal and Mineral Fluids," in *Mercury in the Environment*, USGS Professional Paper 713, pp 25-28 (1970).

133. Bertine, K.K., and Goldberg, E.D., "Fossil Fuel Combustion and the Major Sedimentary Cycle," *Science, 173*, pp 233-35 (1971).

134. Committee for Environmental Information, "Mercury in the Air," *Environment, 13,* No. 4, pp 24-3 (1971).

135. Cranston, R.E., and Buckley, D.E., "Mercury Pathways in a River and Estuary," *Environmental Science, and Technology, 6*, No. 3, pp 274-278 (1972).

136. Weiss, H.V., Koide, M., and Goldberg, E.D., "Mercury in Greenland Ice Sheet: Evidence of Recent Input by Man," Unpublished manuscript referenced in a draft of the Preliminary Report of the Task Group on Major Ocean Pollutants, for the IDOE Marine Environment Quarterly Study, Washington, D.C., NAS-NRC Ocean Affairs Board.

137. Klein, D.H., and Goldberg, E.D., "Mercury in the Marine Environment," *Environmental Science and Technology, 4*, pp 765-68 (1970).

138. Jenne, E.A., "Atmospheric and Fluvial Transport of Mercury," in *Mercury in the Environment,* Geological Survery Professional Paper 713, pp 40-45 (1970).

139. Young, D.R., *Mercury in the Environment: A Summary of Information Pertinent to the Distribution of Mercury in the Southern California Bight*, Southern California Coastal Water Research Project, 1100 Glendon Ave., Los Angeles, California (1971).

140. Hall, S., "Lead Pollution and Poisoning," *Environmental Science and Technology, 6,* No. 1, pp 30-35 (1972).

141. Patterson, C.C., "Contaminated and Natural Lead Environments of Man," *Archives of Environmental Health, 11,* pp 344-360 (1965).

142. Mills, A.L., "Lead in the Environment," *Chemistry in Britain, 7*, No. 4, pp 160-162 (1971).

143. Friberg, Lars, Piscator, M., and Nordberg, G., *Cadmium in the Environment*, CRS Press, Cleveland, Ohio, (1971).

144. Tucker, Anthony, The Toxic Metals, Ballantine Books, New York (1972).

145. Yamagata, N., Shigematisu, I., "Cadmium Pollution in Perspective," Bulletin Inst. of Public Health (Tokyo), 19, No. 1, p 1 (1970).

146. Stokinger, H.E., "The Spectre of Today's Environmental Pollution, United States of America Brand: New Perspectives from an Old Scout," American Journal of Industrial Hygiene Association, 30, No. 3, p 195 (1969).

147. Lutz, C.A., et. al. Design of an Overview System for Evaluating the Public Health Hazards of Chemicals in the Environment, Volume I, Test Case Studies, Battelle Memorial Institute, Columbus, Ohio (1967).

148. International Commission on Radiological Protection, "Report of Committee II on Permissible Dose for Internal Radiation," Stockholm, Sweden (1959).

149. National Committee on Radiation Protection, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, National Bureau of Standards, Handbook 69, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., June 5, 1959.

150. Straub, Conrad P., Low-Level Radioactive Wastes, Division of Technical Information, United States Atomic Energy Commission, (1964).

151. Glasstone, S., Principle of Nuclear Reactor Engineering, D. Van Nostrand Company, Inc., Princeton, New Jersey (1955).

152. Tswoglou, Ernest C., "Nuclear Power: the Social Conflict," Environmental Science and Technology, 5, No. 5, pp 404-410 (1971).

153. Fair, G.M. and Geyer, J.C., Water Supply and Wastewater Disposal, John Wiley and Sons, Inc., New York (1954).

154. Straub, C.P., "Limitations of Water Treatment Methods for Removing Radioactive Contaminants," Public Health Reports, 70, p 897 (1955).

155. Eden, G.E., Elkins G.H.J., and Truesdale, G.A., "Removal of Radioactive Substances from Water by Biologic Treatment Processes," Atomics and Atomic Technology, 5, p 133 (1954).

156. Lauderdale, R.H., "Treatment of Radioactive Water by Phosphate Precipitation," Ind. Chem. Eng., 43, p 1538 (1951).

157. Lacy, W.J., "Removal of Radioactive Material from Water by Slurrying with Powdered Metal," Journal of the American Water Works Association, 44, p 824 (1952).

158 Straub, C.P., Morton, R.J. and Placak, O.R., "Studies on the Removal of Radioactive Contaminants from Water," Journal of the American Water Works Association, 43, p 713 (1951).

159. Brackett, T.W., and Placak, O.R., "Removal of Radioisotopes from Waste Solutions by Soils - Soil Studies with Conasauga Shale," Proceedings of the 8th Industrial Wastes Conference, Purdue University, May 4,5, and 6, 1953, Purdue University Extension Series No. 83, pp 393-409, Purdue University, Lafayette, Ind., Jan. 1954.

160. Straub, C.P. and Krieger, H.L., "Removal of Radioactive Waste Solutions - Soil Suspension Studies," Proceedings of the 8th Industrial Wastes Conference, Purdue University, May 4,5, and 6, 1953, Purdue University Extension Series No. 83, pp 415-438, Purdue University, Lafayette, Ind., Jan. 1954.

161. Lacy, W.J., "Decontamination of Radioactively Contaminated Water by Slurrying with Clay," Ind. Chem. Eng., 46, p 1061 (1954).

162. Gemmell, L.G., Nucleonics, 10, No. 10, p 40 (1952).

163. Glayna, E.F., "Radioactive Contaminated Laundry Waste and Its Treatment," Sanitary Engineering Conference Held at South District Filtration Plant, City of Chicago, USAEC Report WASH-129, pp 9-24, Sept. 11, 1952.

164. Renn, C.E., "Summary of Off-Site Research and Development," Sanitary Engineering Conference, Baltimore, Maryland, April 15-16, 1954, USAEC Report WASH-275, pp 76-80, Division of Reactor Development, August 1955.

165. National Committee on Radiation Protection, Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentration in Air and Water, National Bureau of Standards Handbook 52, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., March 20, 1953.

166. Anonymous, "Recommendations of the International Commission on Radiological Protection," British Journal of Radiology, Supplement 6, London (1955).

167. Milone, M., Cetini, G., and Ricca, F., "Elimination of Traces of Radioactive Elements from Aqueous Solutions," Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, Vol. 18, pp 133-137, United Nations, New York, (1959).

168. Burns, R.H., "Radioactive Waste Control at the United Kingdom Atomic Energy Research Establishment, Howell," Disposal of Radioactive Wastes, Proceedings Conference, Volume I, International Atomic Energy Agency, Vienna, Austria, p 413 (1960).

169. Foltermayer, E., "The Energy Joy Ride is Over," Fortune, p 99, September, (1972).

170. Loff, G.O.G., and Ward, J.C., "Economics of Thermal Pollution Control," WPCF JOURNAL, 42, p 2102 (1970).

171. Kastenbader, P.D., and Flecksteiner, J.W., "Biological Oxidation of Coke Plant Weak Ammonia Liquor," WPCF JOURNAL, 41, p 199 (1969).

172. Gannon, J.P., "Steam-Carried Pollutant Get U.S. Steel in Hot Water with Pittsburgh Air Board," The Wall Street Journal, Nov. 18, 1971.

173. Hanks, Thrift G., Solid Waste/Disease Relationships; a Literature Survey, Public Health Service Publication No. 999-UIH-6, Solid Wastes Program, Cincinnati (1967).

174. Smith, D.T., Conant, N.F., and Willett, H.P., Zinsser Microbiology, Appleton-Century-Crofts, New York (1968).

175. Clarke, N.A., and Berg, G., et. al., "Human Enteric Viruses: Source, Survival, and Removability in Wastewater," WPCF JOURNAL, 43, No. 3, p 249 (1962).

176. Rhodes, A.J. and Van Rooyen, C.E., Textbook of Virology, Williams and Wilkins, Baltimore (1968).

177. Brezenski, F.T., Russomanno, R., and De Falco, P., "The Occurrence of Salmonella and Shigella in Post-Chlorinated and Non-Chlorinated Sewage Effluents and ReceivingWaters," (1965).

178. Klein, Louis, River Pollution; Volume III, Control, Butterworths, Washington, (1966).

179. Anderson, Myron S., "Fertilizing Characteristics of Sewage Sludge," Sewage and Industrial Wastes, 41, No. 6, pp 678-682 (1959).

180. Stekinger, Herbert E., and Woodward, R.L., "Toxicologic Methods for Establishing Drinking Water Standards," Journal of the American Water Works Association, 50, pp 515-529 (1958).

181. Henderson, John M., "Agricultural Land Drainage and Stream Pollution," Journal Sanitary Engineering Div. Proceedings American Society of Civil Engineers, 88, No. SA6, pp 61-74 (1962).

182. Anderson, R.L., et. al., "Utilization of Municipal Wastewater Sludge," WPCF JOURNAL, p 29 (1971).

183. Huebner, R.J., et. al., "Rickettsiapox - A Newly Recognized Rickettsial Disease (IV)," Public Health Reports, 61, No. 47, pp 1677, (1946).

184. Clarke, N.A. and Kahler, P.W., "The Inactivation of Purified Coxsackie Virus in Water by Chlorine, "American Journal of Hygiene, 59, pp 119-127, (1954).

185. Stone, R., and Gupta, R., "Aerobic and Anaerobic Landfill Stabilization Process," Journal of Sanitary Engineering Div. Proceedings American Society of Civil Engineers, 96, No. SA6, p 1939 (1970).

186. Lanoni, A.E., Ground Water Pollution from Sanitary Landfills and Refuse Dump Grounds, Research Report 69, Department of Natural Resources, State of Wisconsin, Madison (1971).

187. Quasim, S., and Burchinal, J.C., "Leaching from Simulated Landfills," WPCF JOURNAL, 42, No. 3, p 371 (1970).

188. Cook, H.A., Cromwell, D.A., and Wilson, H.A., "Microorganisms in Household Refuse and Seepage Water from Sanitary Landfills," Proceedings West Virginia Academy of Science, 39, p 107 (1967).

189. American Public Works Association, Municipal Refuse Disposal, Public Administration Service, Chicago (1970).

190. Cummins, R.L., Effects of Land Disposal of Solid Wastes on Water Quality, Report SW-2ts, U.S. Department of Health, Education, and Welfare, National Center for Urban and Industrial Health, Solid Wastes Program, Cincinnati, Ohio (1968).

191. Anonymous, "Rules and Regulations for Administration of the Pennsylvania Solid Waste Management Act," adopted by the Pennsylvania State Health Department.

192. California State Department of Public Health, Status of Solid Waste Management, Interim Report, September (1968).

193. U.S. Department of Health, Education, and Welfare, Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health, Parts 1 and 2, Washington, D.C., U.S. Government Printing Office (1969).

194. Huang, Ju-Chang, and Liao, Cheng-Sun, "Adsorption of Pesticides on Clay Minerals," Journal of Sanitary Engineering Div. Proceedings American Society of Civil Engineers, 96, No. SA5, pp 1057 - 1078 (1970).

195. Eye, J.D., "Aqueous Transport of Dieldrin Residues in Soils," WPCF JOURNAL, 39, pp 1259 - 1277 (1967).

196. Cliath, M.M., and Spencer, W.F., "Dissipation of Pesticides from Soils by Volatilization of Degradation Products," Environmental Science and Technology, 6, No. 10, pp 910 - 914 (1972).

197. Stickel, Lucille F., Organochlorine Pesticides in the Environment, Special Scientific Report - Wildlife No. 119., U. S. Department of the Interior, Washington, D. C., (1968).

198. Leigh, G.M., "Degradation of Selected Chlorinated Hydrocarbon Insecticides," WPCF JOURNAL, 41, No. 11, pp R450-R460 (1969).

199. Hill, D.W., and McCarty, P.L., "Anaerobic Degradation of Selected Chlorinated Hydrocarbon Pesticides," WPCF JOURNAL, 39, pp 1259-1277 (1967).

200. Swoboda, A.R., et. al., "Distribution of DDT and Taxaphene in Houston Black Clay on Three Watersheds," Environmental Science and Technology, 5, No. 2, pp 141-145 (1971).

201. Woodward, R.L, "Significance of Pesticides in Water Supplies," Journal of the American Water Works Association, 52, pp 1367-1372 (1960).

202. Westlake, W.E., and Gunther, F.A., "Occurrence and Mode of Introduction of Pesticides in the Environment," in Organic Pesticides in the Environment, American Chemical Society, Washington, D.C. (1966).

203. McKee, J.E. and Wolf, H.W., Water Quality Criteria, 2d ed., Water Resources Agency of California, State Water Quality Control Board Publication 3A, Sacramento, (1963).

204. Gerhardt, P.D., and Witt, J.M., Summary of Downwind Drift Limits, Comparison of Dust vs. Spray, Pesticide Residue Study, Department of Entomology, University of Arizona (1963).

205. Yeo, D., "The Problem of Distribution; The Physics of Falling Droplets and Particles, The Drift Hazard," in *First International Agricultural Aviation Conference,* (1959).

206. Akesson, N.B., and Yates, W.E., "Problems Relating to Application of Agricultural Chemicals and Resulting Drift Residues," *Annual Rev. Entomol., 9,* pp 285-318 (1964).

207. Zeeman, N., "Everyman's Garden of Pesticides," *Environmental Quality, 3,* No. 2, pp 29-33 (1972).

208. Bhattacharyya, S., "Urban and Radioactive Wastes - A Common - Sense Solution," *Frontier, 30,* No. 1, p 30 (1970).

209. Klein, L., *River Pollution, Volume II,* Butterworths, London (1962).

210. National Technical Advisory Committee, *Water Quality Criteria,* Report to the Secretary of the Interior, U.S. Government Printing Office, Washington, D.C. (1968).

211. Vandergrift, A.E., Shannon, L.J., Sallee, E.E., Gorman, P.G., and Park, W.R., "Particulate Air Pollution in the United States," *APCA JOURNAL, 21,* p 321 (1971).

212. Serber, E.W., "Biological Effects of Pollution in Michigan Waters," *Sewage and Industrial Wastes, 25,* pp 79-86 (1953).

213. Sussman, V.H., in *Air Pollution, Volume III, 2d ed.*, Stern, A.C., ed., Academic Press, New York (1968).

214. Nelson, K.W., in *Air Pollution, Volume III, 2d ed.*, Stern, A.C., ed., Academic Press, New York (1968).

215. Wantink, G.R., and Etzel, J.E., "Removal of Metal Ions by Soil," *WPCF JOURNAL, 44,* No. 8, pp 1561-1574 (1972).

216. U.S. Environmental Protection Agency, *An Investigation of Techniques for Removal of Chromium from Electroplating Wastes,* Water Pollution Control Research Series (1971).

217. Truax-Traer Coal Co., *Control of Mine Drainage from Coal Mine Mineral Wastes,* Environmental Protection Agency Project No. 14010DDH, U.S. Government Printing Office, Washington, D.C. (1971).

218. Harrison, A.D., "The Effect of Sulfuric Acid Pollution on the Biology of Streams in the Transvaal, South Africa," Verh. Int. Ver. Limnol., 13, p 603 (1958).

219. Armco Steel Corporation, Limestone Treatment of Rinse Waters from Hydrochloric Acid Pickling of Steel, Environmental Protection Agency Project No. 1201 ODUC, U.S. Government Printing Office, Washington, D.C. (1971).

220. American Oil Company, Fluid Bed Incineration of Petroleum Refinery Wastes, Environmental Protection Agency Project No. 12050EKT, U.S. Government Printing Office, Washington, D.C. (1971).

221. National Canners Association, Dry Caustic Peeling of Tree Fruit for Liquid Waste Reduction, Environmental Protection Agency Project No. 12860FQE, U.S. Government Printing Office, Washington, D.C. (1970).

222. Environmental Protection Agency, The Economics of Clean Water, Volumes I, II, III Summary, Washington, D.C. (1972).

223. Eckenfelder, W.W., and Adams, C.E., "Design and Economics of Joint Wastewater Treatment," Journal of Sanitary Engineering Div. Proceedings American Society of Civil Engineers, 98, No. SA1 (1972).

224. Mar, B.W., "Sludge Disposal Alternatives-Socio-Economic Considerations," WPCF JOURNAL, 41, No. 4, p 547 (1969).

225. Ewing, B.B., and Dick, R.I., "Disposal of Sludge on Land," in Water Quality Improvement by Physical and Chemical Processes, University of Texas Press, Austin (1970).

226. Ralph Stone and Co., Inc., Unpublished Research Data for the Environmental Protection Agency, Contract No. S801582.

227. Ralph Stone and Co., Inc., Industrial Waste Profile No. A, Textile Mill Products, U.S. Department of the Interior, Federal Water Quality Control Administration (1967).

228. Fisher, R.A., Cannery Waste Treatment by Activated Sludge, U.S. Department of the Interior, Federal Water Pollution Control Research Series (1969).

229. U.S. Environmental Protection Agency, Treatment of Citrus Processing Wastes, Water Pollution Control Research Series (1970).

230. U.S. Environmental Protection Agency, Liquid Wastes from Canning and Freezing Fruits and Vegetables, Water Pollution Control Research Series (1971).

231. U.S Environmental Protection Agency, *Demonstration of a Full Scale Waste Treatment System for a Cannery,* Water Pollution Control Research Series (1971).

232. U.S. Environmental Protection Agency, *Complete Mix Activated Sludge Treatment of Citrus Process Waste,* Water Pollution Control Research Series (1971).

233. U.S. Department of the Interior, *The Cost of Clean Water, Volume III, Motor Vehicle and Parts,* Federal Water Pollution Control Association (1967).

234. U.S. Environmental Protection Agency, *Phosphorus Removal by an Activated Sludge Plant,* Water Pollution Research Series (1970).

235. U.S. Department of the Interior, *The Cost of Clean Water, Volume III, Plastic Materials and Resins,* Federal Water Pollution Control Association (1967).

236. Fair, G.M., and Geyer, J.C., *Water Supply and Wastewater Disposal,* John Wiley and Sons, Inc., New York (1967).

237. U.S. Environmental Protection Agency, *Trickling Filter Treatment of Fruit Processing Wastewaters,* Water Pollution Control Research Series (1971).

238. Ralph Stone and Co.Inc, *Industrial Waste Profile for a Total Environment, Leather Tanning and Finishing,* U.S. Department of the Interior, Federal Water Pollution Control Administration (1967).

239. Quirk, T.P., and Hellman, J., "Activated Sludge and Trickling Filtration Treatment of Whey Effluents," *Proceedings, Second National Symposium on Food Processing Waste*, Water Pollution Control Research Series, pp 447-499 (1971).

240. U.S. Environmental Protection Agency, *Whey Effluent Packed Tower Trickling Filtration*, Water Pollution Control Research Series (1971).

241. Baker, D.A., and White J., "Treatment of Packing Waste Using DVC Trickling Filters," Proceedings, *Second National Symposium on Food Processing Wastes,* Water Pollution Control Research Series, pp 289-312 (1971).

242. U.S. Environmental Protection Agency, *Anaerobic Treatment of Synthetic Organic Wastes,* Water Pollution Control Research Series (1972)

243. California Department of Water Resources, *Removal of Nitrate by an Algal System,* Water Pollution Control Research Series (1971).

244. U.S. Environmental Protection Agency, Aerated Lagoon Treatment of Sulfite Pulping Effluents, Water Pollution Control Research Series (1970).

245. Michel, R.L., "Construction Grants and Engineering Branch," Federal Water Quality Administration.

246. U.S. Environmental Protection Agency, Anaerobic Treatment of Synthetic Organic Wastes, Water Pollution Control Research Series (1972).

247. U.S. Environmental Protection Agency, Limestone Treatment of Rinse Waters from Hydrochloric Acid Pickling of Steel, Water Pollution Control Research Series (1971).

248. U.S. Department of the Interior, Neutralization of High Ferric Iron Acid Mine Drainage, Federal Water Quality Administration (1970).

249. U.S. Department of the Interior, Investigation of a High-Pressure Foamy Wastewater Treatment Process, Federal Water Quality Administration, Water Pollution Control Research Series (1970).

250. U.S. Environmental Protection Agency, Liquid Wastes from Canning and Freezing Fruits and Vegetables, Water Pollution Control Research Series (1971).

251. U.S. Department of the Interior, The Cost of Clean Water, Volume III, Industrial Waste Profile, No. 1, Federal Water Pollution Control Association (1967).

252. U.S. Environmental Protection Agency, Bio-Regenerated Activated Carbon Treatment of Textile Dye Wastewater, Water Pollution Control Research Series (1971).

253. U.S. Environmental Protection Agency, An Investigation of Techniques for Removal of Chromium from Electroplating Wastes, Water Pollution Control Research Series (1971).

254. U.S. Department of the Interior, Treatment of Acid Mine Drainage by Reverse Osmosis, Federal Water Quality Administration, Water Pollution Control Research Series (1970).

255. U.S. Environmental Protection Agency, Ultrathin Membranes for Treating Metal Finishing Effluents by Reverse Osmosis, Water Pollution Control Research Series (1971).

256. Hauck, A.R., and Sourirajan, S., "Reverse Osmosis Treatment of Diluted Nickel Plating Solutions," WPCF JOURNAL, 44, No. 7, pp 1372-1383 (1972).

257. U.S. Environmental Protection Agency, *Reverse Osmosis Concentrations of Dilute Pulp and Paper Effluent*, Water Pollution Control Research Series (1972).

258. Edmigten, N.G., and Runyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources," *APCA JOURNAL, 20,* No. 7, p 446 (1970).

259. Anonymous, "Air Pollution Control Expenditures in the Chemical Industry," *APCA JOURNAL, 19*, No. 4, p 278 (1969).

260. Lund, H.F., "Industrial Air Pollution Control Equipment Survey: Operating Cost and Procedures," *APCA JOURNAL, 19*, No. 5, p 315 (1969).

261. Lewis, C.J., and Cracker, B.B., "The Lime Industry Problem of Airborne Dust," *APCA JOURNAL, 19*, p 31 (1969).

262. National Coal Association, "Modern Dust Collection," NCA Fuel Engineering Data, Section F-2, Washington, D.C. (1962).

263. Day and Zimmerman Association, *Air Pollution Study of Municipal Incinerator Effluent Gases,* Special Studies for Incineration No. 5, Government of the District of Columbia, Dept. of Sanitary Engineering, Philadelphia (1967).

264. Caykendall, J.W., Spencer, E.F., and York, O.H., "New High-Efficiency Mist Collector," *APCA JOURNAL, 18,* p 315 (1968).

265. Hardison, L.C., "Techniques for Controlling the Oxides of Nitrogen," *APCA JOURNAL, 20,* p 377 (1970).

266. George, R.E., Verssen, J.A., and Chass, R.L., "Jet Aircraft: A Growing Pollution Source," *APCA JOURNAL, 19,* p 847 (1969).

267. Executive Office of the President, Office of Management and the Budget, *Standard Industrial Classification Manual*, U.S. Government Printing Office, Washington, D.C. (1972).

268. Leontief, Wassily, "Environmental Repercussions and the Economic Structure: an Input-Output Approach," *The Review of Economics and Statistics, 52,* No. 3, pp 262-271 (1970).

269. Zimmer, Charles, R.I., "Calculating Air Quality and its Control," *APCA JOURNAL, 15,* No. 5, pp 565-572 (1965).

270. Russel, Clifford S., and Spofford, W.O., A Quantitative Framework for Residuals Management Decisions, Johns Hopkins Press (1972).

271. Grant, Eugene L., Principles of Engineering Economy, The Ronald Press Company, New York (1938).

272. United States Department of Commerce, Bureau of the Census, 1967 Census of Manufacturers, U.S. Government Printing Office, Washington, D.C. (1970).

273. U.S. Department of Commerce, Bureau of the Census, Survey of Current Business, 52, No. 8 (1972).

274. Private Communication, Eric E. Lemke, Engineering Director, Los Angeles County Air Pollution Control District, January 17, 1973.

275. U.S. Department of Commerce, Statistical Abstract of the U.S.: 1971, 92nd ed., Washington, D.C. (1971).

276. U.S. Department of Health, Education, and Welfare, Report of the Secretaries Commission on Pesticides and their Relationship to Environmental Health, United States Government Printing Office, Washington, D.C. (1969).

277. Butchbaker, J.E., Gartun, G.W., Mahoney, W.A., and Paine, M.D., Evaluation of Beef Cattle Feedlot Waste Management Alternatives, for the Office of Research and Monitoring, U.S. Environmental Protection Agency, Grant No. 13040 FRG, U.S. Government Printing Office (1971).

278. Haagen-Smit, A.J., The State of California Implementation Plan for Achieving and Maintaining the National Ambient Air Quality Standards, Section VI, the California Air Resources Board (1972).

279. U.S. Department of the Interior, Secondary Treatment of Potato Processing Wastes, Pacific Northwest Water Laboratory, Federal Water Pollution Control Administration (1969).

280. Neil, J.H., "Some Effects of Potassium Cyanide on Eastern Brook Trout (Salvelinus fontinalis)," Fourth Ontario Industrial Waste Conference (1957).

281. U.S. Department of Health, Education, and Welfare, Air Pollution in the Coffee Roasting Industry, U.S. Public Health Publication No. 999-AP-9, U.S. Public Health Service Division of Air Pollution, Cincinnati, Ohio (1964).

282. Mayer, M., A Compilation of Air Pollutant Emission Factors for Combustion Processes, Gasoline Evaporation, and Selected Industrial Processes, U.S. Public Health Services, Cininnati, Ohio (1965).

283. McMichael, W.F., Kruse, R.E., and Hill, D.M., APCA JOURNAL, 18, p 246 (1968).

284. Jens, W., and Rehm, F.R., Proceedings of the National Incinerator Conference, p 74, American Society of Mechanical Engineers, New York (1966).

285. Walker, A.B., and Schmitz, F.W., Proceedings of the National Incinerator Conference, p 64, American Society of Mechanical Engineers, New York (1966).

286. Engdahl, R.B., in Air Pollution, Volume III, 2nd ed., Stern, A.C., ed., Academic Press, New York (1968).

287. Kanter, C.V., Mills, J.L., Leudthe, K.O., Ingels, R.M., Linnard, H., and Newmark, P., Emission of Oxides of Nitrogen from Stationery Sources in Los Angeles County, Report No. 4, Los Angeles County Air Pollution Control District, Los Angeles (1961).

288. Hein, D.M., and Engdahl, R.B., A Study of Effluents from Domestic Gas-Fired Incinerators, American Gas Association, New York (1959).

289. Parthasaradby, N.V., "A Survey of Methods for Treatment of Effluents in Electroplating Industry,' Environmental Health, 11, pp 358-365 (1969).

290. Hershaft, A., "Solid Waste Treatment Technology," Environmental Science and Technology, 6, No. 5, pp 412-421 (1972).

291. International Commission on Radiological Protection, Principles of Environmental Monitoring Related to the Handling of Radioactive Materials, Pergamon (ICRP Publication No. 7), Oxford (1965).

292. International Atomic Energy Agency, Radioactive Waste Disposal into the Sea, Vienna, Safety Series No. 5 (1961).

293. Imhoff, K., and Fair, G.M., Sewage Treatment, John Wiley and Sons, Inc. New York (1940).

294. Edinger, J.E., Brady, D.K., and Graves, W.L., "The Variation of Water Temperatures Due to Steam Electric Cooling Operations," WPCF JOURNAL, 40, No. 9, pp 1632-1639 (1968).

295. Van der Hoist, J.M.A., "Waste Heat Use in Greenhouses," WPCF JOURNAL, 44, No. 3, pp 494-496 (1972).

296. U.S. Department of Commerce, Bureau of the Census, Survey of Current Business, 49, No. 11 (1969).

299. The California Air Resources Board, The State of California Implementation Plan for Achieving and Maintaining the National Ambient Air Quality Standards (1972).

300 Southern California Association of Governments, Interim Open Space Element of the Southern California Regional Development Guide (1970).

301. Air Pollution Control District, County of Los Angeles, Profile of Air Pollution Control (1971).

302. California Regional Water Quality Control Board, Los Angeles Region, Interim Water Quality Plan for the Santa Clara River and Los Angeles River Basins (Basin 4A and Basin 4B) (1971).

303. California Regional Water Quality Control Board, Santa Ana Region, Interim Water Quality Plan for the Santa Ana River Basin (Basin 8) (1971).

304. Public Notice of the Board of Public Works, City of Los Angeles (public hearing regarding proposed amendments to "Rules and Regulations Governing Disposal of Industrial Wastes to the Sanitary Sewer and Storm Drain Systems of the City of Los Angeles,") (Hearing date, November 20, 1972).

305. Bureau of the Census, County Business Patterns, 1971.

306. City of Los Angeles, Bureau of Engineering, Donald C. Tillman City Engineer, Sludge Disposal Alternatives for the City of Los Angeles (Preliminary) (1972).

307. Ralph Stone and Company, Inc., Sewage Sludge Handling and Disposal Feasibility Study for Ventura Regional County Sanitation District (1972).

308. Bagwell, F. A., Rosenthat, K, E., Teixeira, D. P., Breen, B. P., Bayard De Vole, N., Kerho, S., "Utility Boiler Operating Modes for Reduced Nitric Emissions," Journal of the Air Pollution Control Association, 21, No. 11, p 702 (1971).

309. Chass, R. L., Krenz, W. B., Nevitt, J. S., and Danielson, J.A., "Los Angeles County Acts to Control Emissions of Nitrogen Oxides from Power Plants," Journal of the Air Pollution Control Association, 22, No. 1, p15(1972).

310. Dreyfuss, John, "U. S. Clean Air Plan Proposes Gasoline Rationing in Southland," Los Angeles Times, p 1, December 8, 1972.

311. Los Angeles Department of Water and Power, Water for Los Angeles (1971).

312. Los Angeles, Portrait of an Extraordinary City, Editors of Sunset Books and Sunset magazine, Johnson, Paul C., supervising editor, Menlo Park, Calif. Lane Magazine and Book Company, 1968.

313. State of California, Senate Bill No. 5 Approved by Governor and Filed with Secretary of State, July 13, 1972.

314. Santa Ana Watershed Planning Agency, Summary of Data on Treatment Facilities for Water and Wastewater - 1970, Riverside, California (1971).

315. Ludzack, F.J., and Noran, D.K., "Tolerance of High Salinities by Conventional Wastewater Treatment Processes," Journal Water Pollution Control Federation, 37, No. 10, pp 1404 - 1416 (1965).

316. Bernstein, L. Quantitative Assessment of Irrigation Water Quality with Reference to Soil Properties, Climate, Irrigation Management, and Salt Tolerance of Plants, A.S.T.M. STP-416 (1967).

317. Linter, A.M., and Long, L. Jr., "Sodium p- [1-(- Nonylthio) Ethyl] Benzene Sulfonate; A New Third Generation Biodegradable Surfactant," Journal American Oil Chemistry Society, 46, p 601 (1969).

318. Beeckmans, I., "Removal of Detergents from Water," CEBEDEAU (Belgium), 22, p 125 (1969).

319. Osborne, D.W., "Difficulties Associated with Sludge Digestion with Particular Reference to Synthetic Detergents," Water Pollution Control, (Britain), 68, p 662 (1969).

320. Solon, J.M., Lineer, J.L., and Nair, J.H., IV., "The Effects of Sublethal Concentrations of L.A.S. on the Acute Toxicity of Various Insecticides to the Fat Head Minnow (Pimephales Promelas Rafinesque), Water Resources (Britain), 3, p 767 (1969).

321. U.S. Department of Health, Education and Welfare, Public Health Service Drinking Water Standards, 1962 PHS Pub. 956, Washington, D.C.

322. The Envirogenics Co., of Aerojet General Corporation, System Engineering Analysis of Solid Waste Management in the SCAG Region A report to the Southern California Association of Governments, August, 1972.

323. Private Communication, Eric E. Lemke, Engineering Director, Los Angeles County Air Pollution Control District, April 16, 1973.

324. Nemerow, N.L., *Theories and Practices of Industrial Waste Treatment*, Addison-Wesley, Reading, Mass. (1963).

325. Anonymous, "Hazardous Wastes: A 'Powder Keg' Waiting to Blow," *Refuse News*, *VI*, May, 1973.

326. California State Department of Public Health, *Hazardous Waste Disposal Survey* (1971).

327. Private Communication, Eric E. Lemke, Engineering Director, Los Angeles County Air Pollution Control District, April 16, 1973.

328. Culp, R.L., and Culp, G.L., *Advanced Wastewater Treatment*, Van Nostrand and Co., New York (1971).

329. Kneese, A.V., Ayres, R.V., and d'Arge, R.I., *Economics and the Environment: A Materials Balance Approach*, Johns Hopkins Press, Washington (1970).

330. American Public Works Association, Public Administration Service, *Municipal Refuse Disposal* (1966).

331. Hurn, R.W., "Mobile Combustion Sources," in *Air Pollution, Volume III, 2nd Ed.,* Stern, A.C., ed., Academic Press, New York (1968).

332. Environmental Protection Agency, Region IX, *Technical Support Document for the Metropolitan Los Angeles Intrastate Air Quality Control Region*, Washington, D.C.

333. Turk, Amos, "Source Control by Gas-solid Adsorption and Related Processes," in *Air Pollution, Vol. III, 2nd Ed.*, Stern, A.C., ed., Academic Press, New York (1968).

334. James, G.V., *Water Treatment, 4th Ed.*, Chemical Rubber Company Press, Cleveland (1971).

335. The National Environmental Policy Act of 1969, Public Law 91-190, 42 U.S.C. 4321-4347.

336. The Clean Air Act, 42 USC 1857, as amended by Public Laws 90-148, 91-604, and 92-157.

337. The Clean Water Act, 33 U.S.C. 1151, as amended by Public Laws 91-224 and 92-500.

338. Wall Street Journal, p.8, August 1, 1972.

339. Wall Street Journal, p. 14, August 15, 1972.

340. Marine Protection, Research, and Sanctuaries Act of 1972.

341. Wall Street Journal, p.12, October 16, 1972.

342. Council on Environmental Quality, Environmental Quality, Third Report. (1972).

343. Occupational Health and Safety Act.

344. Federal Solid Waste Disposal Act, Public Law 89-272.

345. Anonymous, "Inglewood Creates Total Environmental Planning Process," Dispatch, 3 (1973).

346. Title 23, California Administrative Code.

347. (Same as 348)

348. U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 93rd edition, Washington, D.C. (1972).

349. U.S. Department of Agriculture, Agricultural Statistics, Washington, D.C. (1972).

350. Baumeister, Teodore, ed., Mark's Mechanical Engineers' Handbook, McGraw-Hill, New York (1958).

351. U.S. Department of the Interior, Bureau of Mines, Mineral Facts and Problems, Washington, D.C. (1970).

352. United Nation's Food and Agriculture Organization, Production Yearbook, 25 (1971).

353. Rose, W.W., Pleoceo, W.A., Katsuyama, A., Sternberg, R.W., Braunes, G.V., Olson, N.A., and de Weckel, L. G., "Production and Disposal Practices for Liquid Wastes from Cannery and Freezing Fruits and Vegetables," Proceedings Second National Symposium on Food Processing Wastes, WPC Research Series, p. 109 (1971).

354. U.S. Department of the Interior, Federal Water Pollution Control Administration, Secondary Treatment of Potatoe Processing Wastes, Washington, D.C. (1969).

355. Private Communication, Van Waters and Rogers Company.

356. Private Communication, Mr. Clark, Cabbot Corporation.

357. U.S. Department of the Interior, Bureau of Mines, Minerals Yearbook, Vol. 1, Washington, D.C. (1970).

358. U.S. Department of the Interior, Federal Water Pollution Control Administration, Industrial Waste Profile for a Total Environment, Washington, D.C. (1967).

359. U.S. Department of Commerce, Bureau of the Census, Current Industrial Reports, Washington, D.C. (1972).

360. Leopold, L.B., Clarke, F.E., Hanshaw, B., and Balsey, J., "A Procedure for Evaluating Environmental Impact," U.S. Geological Survey Circular 645.

361. Boubel, R. A. Darley, E.F., and Schuch, E.A., "Emissions from Burning Grass Stubble and Straw," Journal of the Air Pollution Association, 19, p. 497 (1969).

362. Lewis, C.S., Proceedings of the Annual Convention of the National Lime Association, 64 (1966).

363. Chass, R.L., and George, R.E. Journal of the Air Pollution Control Association, 10, p. 34 (1960).

364. U.S. Department of Health, Education, and Welfare, Atmospheric Emissions from Petroleum Refineries: A Guide for Measurement and Control, PHS Pub. 703, Washington, D.C. (1960).

365. O'Mara, R., Iron and Steel Engineering, 30,p. 100 (1953).

366. Thring, M.W., and Sarjant, R.J., Iron and Coal Trades Review, 174, p. 731 (1957).

367. Meadley, A.H., and Calvin, J.G., Iron and Steel Institute (London) Special Report, 61 (1958).

368. Hurn, R.W., "Mobile Combustion Sources," in Air Pollution, Vol. III, 2nd Ed., Stern, A.C., Ed., Academic Press, New York (1968).

369. Kuhlman, A., Staub, 24, p. 121 (1964).

370. Rehm, I.R., Journal of the Air Pollution Control Association, 6 p 199 (1957).

371. Kantes, C.V., Luncke, R.G., and Ludwick, A. P., Journal of the Air Pollution Control Association, 6, p. 191 (1957).

372. Kaiser, E.R., Holitsky, J., Jacobs, M.B., and McCabe, L.C. Journal of the Air Pollution Control Association, 10 (1960).

373. Elkin, H., "Petroleum Refining Emissions," in Air Pollution, Vol. III, 2nd Ed., Stern, A.C., ed., Academic Press, New York (1968).

374. U.S. Department of Health, Education, and Welfare, the Sources of Air Pollution and Their Control, P.H.S. Pub. 1548, Washington, D.C. (1966).

375. Rohrman, L.A., Ludwig, J.H., and Steigerwald, B.J., SO_2 Emissions in the United States (1960), National Center for Air Pollution Control Memorandum (1967).

376. National Academy of Engineering, Abatement of Sulfur Dioxide Emission from Stationary Combustion Sources (1970).

377. Faith, W.L., Los Angeles Air Pollution Board Report, 8 (1954).

378. Gestle, R.W., and Kemnitz, D.A., "Atmospheric Emissions from Open Burning," Journal of the Air Pollution Control Association, 17, p 324 (1967).

379. U.S. Department of the Interior, Federal Water Pollution Control Administration, Industrial Waste Profile for a Total Environment Canned and Frozen Fruits and Vegetables, Washington, D.C. (1967).

380. U.S. Environmental Protection Agency, Current Practice in Seafoods Processing Waste Treatment, WPC Research Series, Washington, D.C. (1970).

381. U.S. Department of the Interior, Federal Water Pollution Control Administration, Textile Mill Products for a Total Environment Washington, D.C. (1967).

382. U.S. Department of the Interior, Federal Water Pollution Control Administration, The Cost of Clean Water Vol. III, No. 2 Washington, D.C. (1967).

383. Kleppe, P.J., and Rogers, C.N., Survey of Water Utilization and Waste Control Practices in the Southern Pulp and Paper Industry, University of North Carolina Water Resources Institute (1970).

384. U.S. Department of the Interior, Federal Water Pollution Control Administration, The Cost of Clean Water, Vol. III, No. 3, Washington, D.C. (1967).

385. U.S. Department of the Interior, Federal Water Pollution Control Administration, The Cost of Clean Water, Vol. III No. 10, Washington, D.C. (1967).

386. Anonymous, "Environmental Effects of Producing Electric Power," Hearings Before the Joint Committee on Atomic Energy 91st Congress, Vol. II (1970)

387. U. S. Environmental Protection Agency, *State of Arkansas Sugar Beef Processing Waste Treatment*, WPC Research Series, Washington, D. C. (1971).

388. U. S. Department of the Interior, Federal Water Pollution Control Administration, *The Cost of Clean Water, Vol. III,* No. 8, Washington, D. C. (1967).

389. Johnson, E. L., and Peniston, Q.P., "Pollution Abatement and By-product Recovery in the Shellfish Industry," Proceedings, Second National Symposium on Food Processing Wastes (1971).

390. Anonymous, *White Water Wastes from Paper and Paperboard Mills: Pollution Sources and Method of Treatment,* (1970). (New England Interstate Water Pollution Control Commission)

391. Johnson, E. L., and Peniston, O. P., "Pollution Abatement and By-product Recovery in the Shellfish Industry," *Proceedings 2nd National Symposium on Food Processing Wastes* (1971).

392. U. S. Department of the Interior, Federal Water Pollution Control Administration, *The Cost of Clean Water, Vol. III,* No. 1, Washington, D. C. (1967).

393. Logsden, J. E., and Robinson, T. L., *Radioactive Waste Discharges to the Environment from Nuclear Power Facilities,* Addendum 1, E.P.A. Office of Radiation Programs, Washington, D. C. (1971).

394. Mills, S. L., Leudtke, K. D., Woolrich, P. I., and Perry, L. B., *Emissions of Oxides of Nitrogen from Stationary Sources in Los Angeles County,* Los Angeles Air Pollution Control District, Report 3 (1961).

395. Vanhaven, F. E., and Segelis, G. G., *Industrial Engineering and Chemistry,* 37, p 816 (1945).

396. Anonymous, *Emissions of Oxides of Nitrogen from Stationary Sources in Los Angeles, County,* Reports 1 and 2 (1960).

397. Anonymous, *Emissions in the Atmosphere from Petroleum Refineries,* Los Angeles Air Pollution Control District Report 7, p 23 (1958).

398. Lund, H. I., ed., *Industrial Pollution Control Handbook,* McGraw-Hill, New York (1971).

399. Nemerow, N. L., *Theories and Practices of Industrial Waste Treatment,* Addison-Wesley, Reading, Massachusetts. (1963).

400. Heukelekian, H., "Treatment of Rice Water," *Industrial and Chemical Engineering, 42,* p 647 (1950).

401. Horton, R. K., Pachelo, M., and Santana, M. I., "Study of the Treatment of the Wastes from the Preparation of Coffee," paper presented at the Inter-American Regional Conference on Sanitary Engineering, Caracas, Venezuela (1946).

402. Masselli, J. W., Masselli, N. W., and Burford, N. G., *A Simplification of Textile Waste Survey and Treatment,* New England Interstate Water Pollution Control Commission (1959).

403. Black, O. R., "Study of Wastes from Synthetic Rubber Industry," *Sewage Works Journal, 18,* p 1169 (1946).

404. Smith, R. S., and Walker, W. W., *Survey of Liquid Wastes from Munitions Manufacturing,* United States Public Health Service, Reprint 2508, Washington, D. C.

405. American Petroleum Institute "1967 Domestic Refinery Effluent Profile" (1968).

406. Masselli, J. W., and Burford, M. G., "Pollution Reduction Program for the Textile Industry," *Sewage and Industrial Wastes," 28,* p 1273 (1956).

407. MIT Study of Critical Environmental Problems, *Man's Impact On the Global Environment,* MIT Press, Cambridge, Mass. (1970).

408. United States Department of Health, Education, and Welfare, "Acid Mine Drainage," report for Committee on Public Works, House of Representatives, 87th Congress, House Committee Print No. 18 (1962).

409. "Cost of Clean Air," First Report to Congress by the Secretary of Health, Education, and Welfare, in Compliance with Public Law 90-148 (1969).

410. "Cost of Clean Air," Second Report to Congress by the Secretary of Health, Education, and Welfare, in compliance with Public Law 90-148 (1970).

411. Water Information Center, *Water Encyclopedia,* New York (1970).

SECTION XII

APPENDIX

Page

Table I: Economic Output of SIC-coded Industries 334

Table II: Physical Output of SIC-coded Industries 338

TABLE I INDUSTRIAL OUTPUT - DOLLARS

SIC Code	Description	Basis	Dollars	Year	Reference
01	Agricultural Production - Crops		\$22,609 × 10^6	1971	276
02	Agricultural Production - Livestock		\$30,454 × 10^6	1971	276
08	Forestry				
10	Metal Mining				
11	Anthracite Mining				
12	Bitum Coal and Lignite Mining				
13	Oil and Gas Extract				
14	Non-metallic Mining except Fuels				
15-17	Construction		\$109,399 × 10^6	1971	276
20	Total (T)		101,737 × 10^6	1971	276
201-202	Meat and Dairy Products	.3971	40,397 × 10^6	1971	347
203	Preserved Fruits and Vegetables	.1123	11,427 × 10^6	1971	347
204	Grain Mill Products	.1102	11,211 × 10^6		347
20 misc.					
21	Tobacco Mfg.		5,346 × 10^6	1970	347
22-23	Textiles	22 only	24,472 × 10^6	1971	276
24	Lumber and Wood Products		13,009 × 10^6	1970	347
26	Paper and Allied Products		25,362 × 10^6	1971	276

TABLE i INDUSTRIAL OUTPUT - DOLLARS (Cont.)

SIC Code	Description	Basis	Dollars	Year	Reference
28	Total (T)		\$ 52,170 × 10^6	1971	276
281	Industrial and Inorganic Chemicals	.3228 × T =	16,836 × 10^6	1971	347
282	Plastic Materials and Synthetics	.1784 × T =	9,306 × 10^6	1971	347
283	Drugs	.1374 × T =	7,195 × 10^6	1971	347
2873	Nitrogenous Fertilizers				
2874	Phosphatic Fertilizers				
2879	Agricultural Chemicals n.e.c.				
2895	Carbon Black	.040 × T =	208 × 10^6	1971	274
2899	Chemical Preparations n.e.c.	.0328 × T =	1,710 × 10^6	1971	274
Misc. 28					
29	Total (T)		25,777 × 10^6	1971	276
291	Petroleum Refining	.9152 × T =	23,590 × 10^6	1971	347
295	Paving and Roofing Material	.0578 × T =	1,489 × 10^6	1971	347
Misc 29					
31	Leather and Leather Products		5,282 × 10^6	1970	347
32	Total (T)		19,766 × 10^6	1971	276
324	Cement, Hydraulic	.0816	1,612 × 10^6	1971	347

TABLE I INDUSTRIAL OUTPUT - DOLLARS (Cont.)

SIC Code	Description	Basis	Dollars	Year	Reference
325	Structural Clay	.0622 x T =	\$ $1,230 \times 10^6$	1971	347
327	Concrete, Gypsum and Plaster Products	.3503 x T =	$6,924 \times 10^6$	1971	347
Misc. 32					
33	Total (T)		$55,083 \times 10^6$	1971	276
331	Blast Furnace and Steel Products	.4701 x T =	$25,897 \times 10^6$	1971	347
332	Iron and Steel Foundries	.0882 x T =	$4,856 \times 10^6$	1971	347
333	Primary Non-Ferrous Metals	.1137 x T =	$6,265 \times 10^6$	1971	347
334	Secondary Non-Ferrous Metals	.0339 x T =	$1,865 \times 10^6$	1971	347
336	Non-Ferrous Foundries-Castings	.0375 x T =	$2,067 \times 10^6$	1971	347
34	Fabricated Metal Products		$38,454 \times 10^6$	1971	276
36	Electrical and Electronic Equipment		$51,706 \times 10^6$	1971	276
37	Transportation Equipment		$79,562 \times 10^6$	1971	276
40	Railroad Transportation				
41	Passenger Transportation				
42	Trucking				
44	Water Transportation				
45	Air Transportation				
491	Electric Services				

TABLE I INDUSTRIAL OUTPUT - DOLLARS (Cont.)

SIC Code	Description	Basis	Dollars	Year	Reference
492	Gas Production and Distribution				
4952	Sanitary Services Including Sewerage				
4953	Refuse Systems				
54	Food Stores				
5541	Gas Stations				
All Others					

a. In many cases only the 2-digit sic code level data were available for 1971, while a breakdown to 3 and 4 digit levels were available for earlier years. In those cases the proportion of the 2-digit level output accounted for by the subsect was multiplied by the 2-digit output for 1971 to get an estimate for the subsection in 1971.

that is - Let T = 1971 2-digit level output
A = sub-sector (3 or 4 digit level) output for year xx
B = 2-digit level output for year xx

Then the fraction in the basis columns A/B
and the Dollar column = $\frac{A}{B} \cdot T$.

Where reference $\overset{p1}{\underline{274}}$ is used, the base year used for the A/B calculation was 1967; where reference $\overset{p14}{\underline{347}}$ was used the base year was 1970.

TABLE II INDUSTRIAL OUTPUT - PHYSICAL

Sic Code	Description	Output Units	Quantity	Year	Reference
01	AGRICULTURAL PRODUCTS- CROPS				
0119	Barley	Bushels	462.5×10^6	1971	276
0115	Corn	Bushels	5540×10^6	1971	276
0119	Oats	Bushels	876×10^6	1971	276
0112	Rice	100 lb Bags	84×10^6	1971	276
0119	Rye	Bushels	50.9×10^6	1971	276
0111	Wheat	Bushels	1640×10^6	1971	276
0132	Tobacco Leaf	Pounds	1707×10^6	1971	276
01	Agricultural Runoff	Liters			
01	Grass Fires	Tons Refuse			
02	AGRICULTURAL PRODUCTS - LIVESTOCK				
	All Cattle	1000's Head on Farms	117,916	1/1/71	348
	Milk Cows	1000's Head on Farms	12,279	1/1/72	348
	Sheep and Lambs	1000's Head on Farms	18,482	1/1/72	348
	Hogs and Pigs	1000's Head on Farms	62,972	12/1/71	348
0241	Fluid Milk	Pounds	$118,640 \times 10^6$	1971	276
0252	Eggs	Cases (30 doz)	199×10^6	1971	276
	Agricultural Runoff	Liters			
	Cattle Days in Feedlots	Cattle - Days			

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
0252	Swine Days in Feedlots	100 lb Swine Days			
08	FORESTRY				
	Forest Fires- Federal and Protected	Acres	$1,719 \times 10^3$		
	Forest Fires - State and Private	Acres	$2,958 \times 10^3$		
	National Forest burned	Acres	117×10^3	1971	349
	Protected burned	Acres	$1,827 \times 10^3$	1971	349
	Unprotected burned	Acres	733×10^3	1971	349
	TOTAL Commercial Forest Land Available		$499,697 \times 10^3$	1970	349
	TOTAL Timber - board/feet on above land		$3,070 \times 10^9$	1970	349
	TOTAL Timber burned[a]	Tons	$32,311 \times 10^3$	1970	349, 350
10	METAL MINING				
1011	Iron Ores	Large Tons	$80,762 \times 10^3$	1971	276
11	ANTHRACITE MINING				
1111	Anthracite Mining	Production Short Tons	8,584	1971	276
12	BITUM.COAL AND LIGNITE				
1211	Bitum. Coal	Production in Short Tons	548,321	1971	276

TABLE II INDUSTRIAL OUTPUT – PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
13	OIL AND GAS EXTRACTIONS				
1311	Crude Petroleum	Barrels (bbl)	$3,478.2 \times 10^6$	1971	276
1321	Natural Gas Plant Liquid	New Supply Production Barrels	623.9×10^6	1971	276
14	NON METALLIC MINING EXCEPT FUELS				
	Crushed Stone	Crushed Steel Tons	876×10^6	1970	351
201, 202	MEAT AND DAIRY PRODUCTS				
2011 2013	Frozen Meats	Pounds #203 Base Boxes	490×10^6	1971	348
2017	Frozen Poultry	Pounds	$2,142 \times 10^6$	1971	348
2021	Butter, Creamery	Pounds	$1,143.6 \times 10^6$	1971	276
2022	Cheese	Pounds	$2,380.4 \times 10^6$	1971	276
2023	Condensed/Evaporated Milk	Pounds	$1,242.7 \times 10^6$	1971	276
2023	Dry Milk	Pounds	$1,495.4 \times 10^6$	1971	276
2011	Meat Packed	Pounds – Carcass Weight	$36,207 \times 10^6$	1971	276
2024	Ice Cream	Tons	$1,134 \times 10^6$	1971	347
2026	Fluid Milk	Tons			
201	Meat Smoked	Tons			

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
201	Hog Dressing (slaughtered)	Tons	$5,440 \times 10^3$	1970	352
2016	Poultry Slaughtered	Pounds	$10,357 \times 10^6$	1971	276
203	PRESERVED FRUITS AND VEGETABLES				
2037	Frozen Vegetables - without potatoes	Pounds	$2,009 \times 10^6$	1971	348
2037	Frozen Potatoes	Pounds	$2,565 \times 10^6$	1971	348
2037	Frozen Juices and Drinks	Pounds	$5,480 \times 10^6$	1971	348
2037	Frozen Fruits and Berries	Pounds	666×10^6	1971	348
203	Processed Vegetables	Tons	34.3×10^6	1971	353
203	Processed Potatoes	Tons	21.9×10^6	1971	354
203	Preserved and Canned Processed Vegetables and Seafoods	Pounds	$14,250.6 \times 10^6$	1968	222
204	GRAIN MILL PRODUCTS				
2041	Wheat Flour	100 lb Sacks	$254,185 \times 10^3$	1968	222
	Total Grain Processed	Tons (@ 56 lbs/bu)			
	Corn Meal Processed	Tons - Grain	$1,419 \times 10^3$	1971	349
	County elevators	Tons - Grain	$205,309 \times 10^3$	1971	349
	Terminal elevators	Tons - Grain			
	Soybeans - Processed	Tons (@ 60 lbs/bu)	$35,080 \times 10^3$	1971	349

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
2041	Barley Flour Milling	Tons	192×10^3	1971	349
OTHER 20	FOOD PRODUCTION - MISC.				
	Frozen Sea Foods	Pounds	362×10^6	1971	347
	Domestic Fish Catch - Total	Pounds	$4{,}969 \times 10^6$	1971	348
	Domestic Fish - Fresh and Frozen	Pounds	$1{,}487 \times 10^6$	1971	348
	Domestic Fish - Canned	Pounds	$1{,}063 \times 10^6$	1971	348
	Domestic Fish - Cured	Pounds	75×10^6	1971	348
	Domestic Fish - Meat and Oil	Pounds	$2{,}344 \times 10^6$	1971	348
	Canned Sea Food	Pounds	$1{,}351.9 \times 10^6$	1971	348
	Cured Sea Food	Pounds	70.9×10^6	1971	348
	Fresh and Frozen	Pounds	$1{,}157.7 \times 10^6$	1971	348
	Fish Oil	Gallons	$33{,}851 \times 10^3$	1971	348
	Oyster Shell - Lime	Tons	110×10^3	1971	348
	Scrap and Meal	Tons	292×10^3	1971	348
2077	Animal Cooking - Misc. Fats and Oils	Pounds	$15{,}071.4 \times 10^6$	1971	276
2076	Vegetable Oils	Pounds	$18{,}465.6 \times 10^6$	1971	276
2061-2	Cane Sugar - Raw	Tons	$1{,}209 \times 10^3$	1968	222
2063	Beet Sugar	Tons	$3{,}467 \times 10^3$	1968	222

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
209	Misc Food Preparations	Pounds	$5,417 \times 10^6$	1968	222
	Tuna - Canned and Cured	Pounds	461×10^6	1971	347
	Bottomfish - Canned and Cured (excl. tuna)	Pounds	938.7×10^6	1971	347
	Shrimp - Canned and Cured	Pounds	22.1×10^6	1971	347
	Coffee Beans - Green	Bags (132.276 lbs each)	$21,654 \times 10^3$	1970	349
		Tons	$1,432 \times 10^3$	1970	349
22	TEXTILE MILL PRODUCTS				
2211	Broad Woven Fabric Mills - Cotton	Linear Yards	$7,454 \times 10^6$	1968	222
2221	Broad Woven Fabric Mills - Manmade	Linear Yards	$5,280 \times 10^6$	1968	222
2231	Broad Woven Fabrics - Wool	Linear Yards	243.3×10^6	1968	222
22	Other Textiles - Federal Reserve	Linear Yards	151.5×10^6	1968	222
	Cotton	Pounds	3.947×10^6	1971	347
	Man-made	Pounds	$6,536 \times 10^6$	1971	347
	Wool	Pounds	191×10^6	1971	347
	Cotton Mills	Bales	$11,507 \times 10^3$	1970	349
	Cotton Mills	Tons at 480 lbs/bale	$2,762 \times 10^3$	1970	349

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
24	LUMBER AND WOOD PRODUCTS				
2421	Lumber	Board Feet	$36,617 \times 10^6$	1971	276
	Lumber	Pounds @ 3500 lb/cord	$118,666 \times 10^6$	1971	276, 350
	Waste - Dry Wood and Bark	Tons			
	Logging Debris and Bark	Tons			
243	Fiber Board Manufacturing	Tons			
	Plywood Manufacturing	Pounds at 3500 lb/cord	$20,348.3 \times 10^6$	1971	347, 350
		Ft^2 3/8" Basis	$16,744 \times 10^6$ ft^2		
26	PAPER AND ALLIED PRODUCTS				
2611	Wood Pulp	Short Tons	$43,960 \times 10^3$	1971	276
263 264 267	Paper and Paper Board	Short Tons	$54,180 \times 10^3$	1971	276
265	Shipping Containers - Corregated and Solid Fibers	Ft^2 Surface Area	$191,832 \times 10^6$	1971	276
266	Building Paper and Board Mills	Short Tons	$4,358 \times 10^3$	1968	222
2611	Wood Pulp	Production Employees	13,000	1970	347
	Building Paper and Mills	Production Employees	54,000	1970	347
	Paper Mills	Production Employees	110,000	1970	347

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
281	INDUSTRIAL INORGANIC CHEMICALS				
2812	Chlorine	Short Tons	9.349×10^3	1971	276
2819	Sulfuric Acid	Short Tons	$29,285 \times 10^3$	1971	276
2819	H_3PO_4 (Phosphoric Acid)	Short Tons	$8,100 \times 10^3$	1971	276
2813	Purge Gas	Short Tons	$13,719 \times 10^3$	1971	276
2816	Phosphorous	Tons	544×10^3	1971	347
281	Total	Production Employees	162,000	1970	347
282	PLASTIC MATERIALS AND SYNTHETICS				
2821-1	Plastic Material	Tons	$9,720 \times 10^3$		222
284	Cellulosics	Tons	255×10^3		275
2821	Vinyl Polymers	Short Tons	$2,038 \times 10^3$		276
2821	Acrylic Paint	Short Tons	$.01 \times 10^6$	1968	
282	Total	Production Employees	132,000	1970	347
283	DRUGS				
283	Total	Production Employees	72,000	1970	347
2873	NITROGENOUS FERTILIZERS				

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
2873	NH_3	Short Tons	$13,719 \times 10^3$		276
2873	Urea	Short Tons	34.8×10^3		
2373	Ammonium Sulfate	Short Tons	282.9×19^3		
2843 2844 2845	Total	Production Employees	26,000	1970	347
2874	PHOSPHATIC FERTILIZERS				
2874	P_2C_5	Short Tons	$4,966 \times 10^3$		276
2871	Super Phosphate and Phosphate	Short Tons	$16,060 \times 10^3$		
2879	AGRICULTURAL CHEMICALS, NOT ELSEWHERE CLASSIFIED				
2895	CARBON BLACK				
2895	Carbon Black	Tons	$1,000 \times 10^3$		355, 356
2899	CHEMICAL PREPARATIONS, NOT ELSEWHERE CLASSIFIED				
2899	Charcoal Manufacturing				
28 Misc.	OTHER 28				

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
284	Total	Production Employees	66,000	1970	347
286	Total	Production Employees	4,000	1970	347
Other Misc 28	Including 2895	Production Employees	92,000	1970	347
291	PETROLEUM REFINING				
291	Crude Petroleum	Barrels	$3,517.5 \times 10^6$	1970	357
2911	Gasoline	Barrels	$2,202.6 \times 10^6$	1971	348
2911	Kerosene	Barrels	87.5×10^6	1971	348
2911	Distillate Fuel Oil	Barrels	912.1×10^6	1971	276
2911	Residual Fuel Oil	Barrels	274.7×10^6	1971	276
2911	Jet Fuel	Barrels	304.7×10^6	1971	276
2911	Liquified Gases including Ethane and Ethylene	Barrels	547.9×10^6	1971	276
2911	Gas Used-in Liquid Refining	Barrels-Cubic Feet	$278,334 \times 10^3$	1970	357
2911	Oil	Barrels-Fresh Feed			
2911	Oil	Barrels-Capacity 1 Day	10.95×10^6	1967	
	Cooling Towers	Gal.Cooling Water			
	Process Trains	Barrels Wastewater			
	Vacuum Jets	Barrels-Vacuum Distillation	131,052	1970	357

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
	Process Loss	Barrels			
295	PAVING AND ROOFING MATERIAL				
2952	Asphalt	Convert to Tons	157.0×10^6		276
2952	Asphalt Roofing	Tons of Saturated Felt	853×10^3 Tons	1971	347
2952	Asphalt and Products	Tons	$30,458 \times 10^3$	1970	357
Misc. 29	OTHER 29				
2992	Lubricants	Barrels	65.5×10^6	1971	357
31	LEATHER AND LEATHER PRODUCTS				
31	Calf and Whole Kip	Skins	$1,621 \times 10^3$	1971	276
	Cattle Hides and Side Kip	Hides and Kips	$20,477 \times 10^3$	1971	276
	Goat and Kid	Skins	$3,148 \times 10^3$	1971	276
	Sheep and Lamb	Skins	$21,385 \times 10^3$	1971	276
	Shoes and Slippers	Pairs	$533,857 \times 10^3$	1971	276
	Finished Leather	Tons	$.85 \times 10^6$	1963	358
	Finished Leather	Updated to 1971 - Tons	1.06×10^6	1971	358

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
324	CEMENT, HYDRAULIC				
3241	Portland Cement, Finished	Barrels	420,339 x 10^3	1971	276
		Tons			
	Concrete				
325	STRUCTURAL CLAY PRODUCTS				
3251	Brick, Unglazed, Common and Faced	Standard Bricks	7,569.7 x 10^6	1971	276
3251	Glazed Bricks	92.08 in 3/Brick Specific Gravity 2.00	516 x 10^3 Tons		276, 350
	Total Ceramic Products	Tons	2393.6 x 10^3 Tons		276, 350
327	CONCRETE, GYPSUM, AND PLASTER PRODUCTS				
3275	Gypsum, Crude	Short Tons	10,437 x 10^3	1971	276
3275	Gypsum, Calcined	Short Tons	10,224 x 10^3	1971	276
327	Concrete Manufacturing	Tons	647 x 10^6 Tons	1970	247
327	Concrete Manufacturing	Yards^3			
329	MISC. NON METALLIC MINERAL PRODUCTS				
3299	Fiber Glass	Tons - input			

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
32 Misc.	OTHER 32				
3231	Glass Containers	Gross	263,780 $\times 10^3$	1971	276
322	Glassware - Pressed or Blown	Gross	225,579 $\times 10^3$	1971	276
331	BLAST FURNACE AND BASIC STEEL PRODUCTS				
3312	Iron and Steel, Scrap	Short Tons	49,169 $\times 10^3$	1971	276
3312	Pig Iron, Excluding Ferrous Alloys	Short Tons	92,213 $\times 10^3$	1970	357
3312	Steel Raw	Short Tons	120,443 $\times 10^3$	1970	276
3312	Steel Mill Products	Short Tons	87,038 $\times 10^3$	1970	276
331	Sintering Coke	Tons	45,700 $\times 10^3$	1970	357
331	Coal Charged in Coke Products	Tons	567,100 $\times 10^3$	1970	357
331	Ferro Alloy Smelting	Tons- Alloy	12,824 $\times 10^3$	1970	357
	Total Iron and Steel Products	Tons	223,727	1970	357
331	Total	Production Employees	485,000	1970	347
332	IRON AND STEEL FOUNDARIES				
3321	Castings, Gray Iron	Short Tons	13,840 $\times 10^3$	1971	276
3321	Castings, Malleable Iron	Short Tons	892 $\times 10^3$	1971	276

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
332	Iron and Steel - Charged	Tons	$145,000 \times 10^3$	1970	357
332	Tons Steel Processed	Tons	$131,514 \times 10^3$	1970	357
332	Total	Production Employees	190,000	1970	347
333	PRIMARY, NON-FERROUS METALS				
3334	Aluminum	Short Tons	$3,925.2 \times 10^3$	1971	276
3331	Primary Smelting a Refining Cu	Short Tons	$1,437.4 \times 10^3$	1971	276
3332-3	Primary Smelting of Pb and Zn	Short Tons	$1,380.1 \times 10^3$	1971	276
	Lead	Tons	690,400	1970	357
	Zinc	Tons	877,811	1970	357
333	Total	Production Employees	53,000	1970	347
334	SECONDARY, NON-FEROUS METALS				
3341	Copper	Short Tons	$1,522.2 \times 10^3$	1971	276
3341	Secondary Aluminum	Short Tons	781×10^3	1970	357
3341	Secondary Aluminum	Chlorine Used in Chlorination			
335	Total	Production Employees	146,000	1970	347

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
336	NON-FERROUS FOUNDRIES (CASTINGS)				
	Brass and Bronze - Tons of Charge Produced	Tons	[illegible]	1970	357
34	FABRICATED METAL PRODUCTS				
34110	Metal Cans, Total	112 Sheets - 14" x 20" or 31,360 in^2 Base Boxes	$161,890 \times 10^3$	1971	359
36	ELECTRIC AND ELECTRONIC EQUIPMENT				
37	TRANSPORTATION EQUIPMENT				
3711 3713	Motor Vehicles, Cars, Trucks, Buses-Sales	Units - Factory Sales	$10,637.7 \times 10^3$	1971	276
3715	Truck Trailers	Units Shipped	103,784	1971	276
3715	Vans	Units Shipped	65,785	1971	276
3715	Trailer Bodies and Chassis-Detachable	Units Shipped	18,509	1971	276
3743	Railroad and Private Freight Cars	Units Shipped	55,307	1971	276
37		(Cars + Others x 2) = Car Body Equivalents	11.1×10^6	1971	276
40	RAILROAD TRANSPORTATION				
	Coal Used	Short Tons	1,000		348

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
40 (cont.)	Fuel Oil Used	Gallons	33×10^6		348
	Diesel Oil	Gallons	$3,924 \times 10^6$		348
	Electricity	KWH	$1,149 \times 10^6$		348
	Revenue and Non-Revenue	Ton Miles	752.2×10^7	1971	276
	Passenger Revenue	Passenger Miles	$8,901 \times 10^6$	1971	276
41	LOCAL AND INTERURBAN PASSENGER TRANSIT				
	Total Vehicles	Travel Distance	$1,120.7 \times 10^9$		348
	Passenger Vehicles	Travel Distance	906.0×10^9		348
	Cars	Travel Distance	901.0×10^9		348
	Buses	Travel Distance	5.0×10^9		348
41	Total Motor Vehicles	Fuel Cons.- Gallons	$92,328 \times 10^6$		348
41	Passenger Vehicles	Fuel Cons.- Gallons	$66,728 \times 10^6$		348
41	Cars	Fuel Cons.- Gallons	$65,784 \times 10^6$		348
41	Buses	Fuel Cons.- Gallons	944		348
4111	Local Transit Lines	Passengers	$5,497 \times 10^6$	1971	276
4111	Inter City Carriers	Passengers	167.3×10^6	1971	276
		Gallon Diesel Fuel Cans			
		Regular Fuel Cans			

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
42	TRUCKING AND WAREHOUSING				
	Trucks	Vehicle Miles	214.7×10^9		348
	Trucks	Gallons	$25,600 \times 10^6$		318
4213	Trucks, Inter-City	Tons Freight	554×10^6	1971	276
44	WATER TRANSPORTATION				
45	AIR TRANSPORTATION				
	Jet Fuel - Domestic	Gallons	$7,885 \times 10^6$	1969	348
	Jet Fuel - International	Gallons	$1,910 \times 10^6$	1969	348
	Gas - Domestic	Gallons	27×10^6	1969	348
	Gas - International	Gallons	97×10^6	1969	348
4511	Certificated Route Carriers	Passenger Miles	135.65×10^9	1971	276
4511	Certificated Route Carriers	Ton Miles	$18,685 \times 10^6$	1971	276
	LTO Cycles				
	Turbines				
	Turbofan				
	Turbojet				
	Pistons				

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
491	ELECTRIC SERVICES				
	Coal Used	Short Tons	32[illegible] x 10^6		348
	Oil Used	42-Gallon Barrels	396 x 10^6		348
	Gas Used	FT^3	3993 x 10^6		348
	Coal Equivalents including Gas, Oil, Nuclear	Short Tons	618 x 10^6		348
	Total Electric Power	KWH	1,717,520 x 10^6	1971	276
	Electric Utilities	KWH	1,613,936 x 10^6	1971	276
	Electricity by Fuel Power	KWH	1,447,941 x 10^6	1971	276
	Electricity by Water Power	KWH	269,580 x 10^6	1971	276
	Bituminous Coal	BTU at 12,290 BTU/lb.	8,062 x 10^{12}		348
492	GAS PRODUCTION AND DISTRIBUTION				
4925	Manufactured and Mixed Gas	Therms	1,451 x 10^6	1971	276
4922	Natural Gas	Therms	156,832 x 10^6	1971	276
	Oil and Gas	FT^3 Gas			
	Oil and Gas	Gallons Oil			
4952	SANITARY SERVICES SEWAGE SYSTEMS	Gal/Year			

TABLE II INDUSTRIAL OUTPUT - PHYSICAL (Cont.)

Sic Code	Description	Output Units	Quantity	Year	Reference
4953	REFUSE SYSTEMS				
	Solid Waste Incinerated	Tons			
54	FOOD STORES				
	Sales	Tons			
5541	GASOLINE SERVICE STATIONS				
	Gas Sold	Gallons			

☆U.S. GOVERNMENT PRINTING OFFICE: 1973 546-310/77 1-3